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Quartermaster Research & Engineering Center, Natick, Mass.
WEAR RESISTANCE OF MILITARY TEXTILES by Louis I. Weiner.
March 1963 57 pp (Textile Series Report No. 125)

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2. Test methods
3. Test equipment
4. Tests
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QUARTERMASTER RESEARCH & ENGINEERING CENTER
Natick, Massachusetts

Clothing & Organic Materials Division

Textile Series
Report No. 125

WEAR RESISTANCE OF MILITARY TEXTILES

by

Louis I. Weiner

U. S. Army Natick Laboratories

Project Reference:
7-93-18-020

March 1963

FOREWORD

The U. S. Army Natick Laboratories have had a continuing interest in research on Wear Resistance going back to the early World War II years, when problems in the supply and distribution of clothing made it obvious that major improvements in logistic support, as well as significant monetary savings, could be obtained by extending the service life of military clothing. The most significant advance in improving the wear resistance of clothing was the development and use of the carded sateen, worn with the filling side to the outside, as the standard fabric for fatigue and combat wear. This was followed by a variety of other developments which, while less dramatic in import, nevertheless led to significant improvements in the wear performance of many types of military textiles. In recent years, the introduction of many new man-made fibers having unusual mechanical and protective properties has led to a re-examination of the status of this work in the field of wear resistance and to a re-emphasis on several aspects of the work that appear promising for the future.

This report contains summaries of some wear resistance studies conducted primarily during 1961 and 1962. It includes sections on test methods, scoring systems, and wear mechanisms and describes wear trials and correlation studies carried out in cooperation with the Army Field Evaluation Agency at Fort Lee, Virginia.

We wish to acknowledge the work of Mr. D. Paul James and Mr. Johnnie Matthews on the wear trials described in Section 4; the work on the Sand Abrader by its developer, Mr. Harry F. Smith; and the work of Mr. Clarence J. Pope, many of whose reports have been abstracted in this summary. We also thank Miss Editha Stone for many helpful technical suggestions and for the careful editing of this report.

S. J. KENNEDY
Director
Clothing and Organic Materials Division

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DALE H. SIELING, Ph.D.
Scientific Director

MERRILL L. TRIBE
Brigadier General, USA
Commanding

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ABSTRACT

This report is a survey of recent work done at the Army Natick Laboratories on the wear resistance of military textiles. It summarizes studies made on test methods and wear mechanisms, and includes the results of some practical wear trials. Two new instruments are described. One measures the snagging resistance of textiles and the other measures an "abrasive" type of wear action which appears to correlate with combat usage.

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WEAR RESISTANCE OF MILITARY TEXTILES

1. Introduction

The increasing number of military applications for blends of man-made and natural fibers and the increasing understanding of the mechanisms of wear have prompted a re-examination of some aspects of the laboratory and field evaluation of textiles to obtain information that might be used to optimize design and to assess levels of serviceability more realistically. Efforts have been made to improve test methods, to examine wear mechanisms, and to carry out practical field wear trials. This report summarizes some of the work that is pertinent to wear studies currently being conducted at the Army Natick Laboratories and stresses developments made within the last few years.

In the area of test methods, progress has been made in the development of equipment for measuring the snagging tendency of textile fabrics and in relating data obtained with this equipment to field experience. In carrying out this work, cognizance was given to the excellent studies conducted in this and other countries on snagging mechanisms and equipment. A new laboratory abrasion test has been developed using sand as the abrading medium. Preliminary studies have shown good agreement between results of this test and those of the wear course at Fort Lee, Virginia. The procedure followed in using the Stoll Flex Abrader has been modified to take into consideration the extreme sensitivity of this instrument to the presence of lubricants in fabrics. Scoring systems used for assessing garment damage have been reviewed and preliminary investigations of a procedure for validating scoring systems in terms of classification of garments for residual wear life have been initiated. Still in progress are studies being conducted by the Army Field Evaluation Agency to increase the severity of the Cotton Fabric Wear Course for some of the heavy weight cotton/nylon fabrics that take an excessively long time to reach an end point, to improve the normality of the wear scores obtained from a heterogeneous group of test subjects, and to develop more objective methods for measuring surface wear. The results of these studies will be reported at a later date.

In the area of wear mechanisms, studies have been conducted to evaluate the contribution of structure to the abrasion resistance of cotton sateen. A pilot investigation has been carried out to determine the possible effects of frictional heat developed at the metal-fiber interface of the Stoll Tester on the flex abrasion resistance of thermoplastic fibrous materials. An appreciable amount of work has been done on the relationship of lubricants and certain types of finishes, such as water repellents, to the flex abrasion resistance of fabrics. A study of the effect of fiber and yarn morphology on the durability of cotton/nylon sateens has been completed.

In the area of practical wear trials, most of the effort has been concerned with an evaluation of the performance of cotton/nylon (Nyco) blends that are being developed to provide thermal protection and of wool blends that are being developed to replace the all-wool worsted serge. In addition, an experiment is under way to obtain a correlation between laboratory abrasion and accelerated field wear.

Summaries of each of these activities are presented here with the hope that the data and findings will be of value and interest to the textile industry, to the producers of textile fibers, and to other government research groups. Studies made by each of these groups have been, in the past, of considerable benefit to Army research.

2. Development of Test and Scoring Methods

a. Pendulum Snag Tester*

There has been a revival of interest in the role of fabric snagging as a precursor to the wear and tear of clothing. This interest has resulted in the development of test instruments (1,2) and in the classification and analysis of the frequency of snagging in worn garments (3).

The US Army Natick Laboratories have been using a modified Boor-Quartermaster Tear Tester (1) for measuring the snag resistance of textile fabrics. The essential modifications of this instrument consist of a snagging point, which is bent at an angle of approximately 90° so that the fibers and/or yarns in the fabric will be lifted up and out of the plane of the fabric in a true snagging action instead of being cut as they would be by a straight needle; a fabric stage that is planar, instead of channeled, to prevent unwanted deformations of the fabric; and a pendulum that includes a micrometer, so that the depth of penetration of the snagging point can be carefully controlled. The modified pendulum system is illustrated in Figure 1. Instead of measuring the force or energy associated with the production of a snag, measurements are made of the depth of penetration of the needle into the fabric surface when the first visible sign of snagging appears. This becomes the end point of the test.

In order to compare the results obtained on the Pendulum Snag Tester with actual snagging as it occurs in the field, a practical trial was made in which two test subjects fitted with "chaps" made of the selected test fabrics walked 20 feet into and out of a dense patch of brambles**(4). The areas of the chaps showing the greatest number of snags were selected for visual and photographic analysis.

In the laboratory, the thickness of the test fabrics was measured under a pressure of 0.625 psi. Since at this pressure high amplitude floats and loose fibers are pressed into the fabric structure, it was anticipated that some snagging might occur at recorded "penetrations" which actually would be above the fabric surface as indicated by the thickness measurement. However, it was felt that the plane determined by thickness would provide a more logical point of reference than the metal stage on which the fabrics were mounted. The stage was used to calibrate the position of the snagging needle with reference to the fabric surface.

* This section was published in almost identical form in the May 1962 issue of the Textile Research Journal.

** Rubus Allegheniensis

Figure 1· Modified pendulum system.

Since snagging in the laboratory is unidirectional while field snagging is multidirectional, the laboratory data that were used for the comparison were based on that fabric placement in relation to the snagging element which produced a snag with the least degree of penetration. In all instances, this was when the motion of the snagging point was perpendicular to the warp yarns of the fabric.

A comparison of the results of the laboratory and field tests is given in Table I.

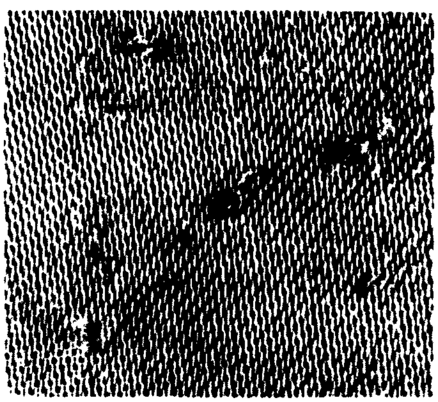
TABLE I

COMPARISON OF LABORATORY AND FIELD SNAGGING

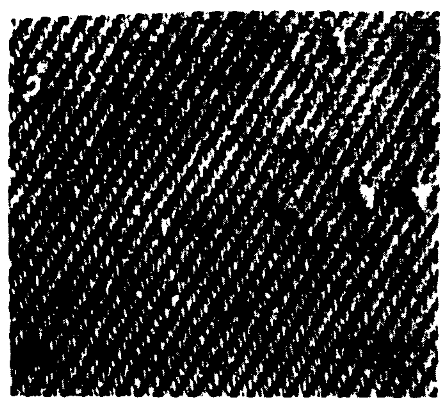
Fabric, Face Out	Depth of Penetration of Snagging Point (in thousandths of inches)	Number of Snags/in^2 in Area of Greatest Snagging
8.2-oz combed cotton twill	5*	7
5.0-oz filament rayon satin	4*	14
8.8-oz carded cotton sateen	0	2
6.0-oz cotton poplin	1	2
9.0-oz cotton oxford	3	2

* Snagging occurred above the theoretical plane of the fabric surface as established by thickness measurements.

Detailed analysis of the field tested chaps revealed significant differences in the mechanisms governing snagging. The rayon satin failed primarily as a result of groups of filaments rupturing and pulling out of the yarn structure. The combed twill failed primarily because its fairly high floats were pulled out of the fabric surface without necessarily being ruptured. The difference in appearance of the snags in the rayon satin and the combed twill is illustrated in Figure 2. A comparison of the face and back of the carded sateen (the standard fatigue fabric used by the military services) showed that fewer snags occurred on the back, which is the side normally worn to the outside of the garment.



5.0-oz rayon satin



8.2-oz combed twill

Figure 2 - Snags produced by brambles (mag. 3x)

In general, the findings of this study agree with the observations of Holmes and Turl on worn garments (3); namely, that filament yarn fabrics have poor resistance to snagging and that float amplitude is more significant than float length as a predisposing factor in snagging. The Pendulum Snag Tester appears to be useful for screening fabrics to determine their resistance to snagging.

b. Snagging by Barbed Wire

The experimental laboratory work with the Pendulum Snag Tester and the field test with "Rubus" suggested that this type of snagging action may not necessarily lead to the severe wear and tear that is associated with combat usage. Accordingly, additional experimental work was undertaken to get an indication of the relative snag resistance of the five fabrics from the initial experiment, but using barbed wire as the snagging agent.

The apparatus used for this investigation consisted of a wooden frame with a base 6 feet long and two supported upright posts located about 2 feet apart near the center of the base. "Gates" randomly covered with barbed wire and approximately 6 inches wide by 2-1/2 feet long were hinged on the posts about 1 foot above the base. Elastic bands attached to the gates and the posts were used to supply sufficient tension to optimize the extent and character of the snagging.

Two test subjects, wearing chaps made of fabric specimens, alternately walked through the gates in a direction opposed to the tension of the elastic bands, which caused the fabric to contact the barbed wire. The test subjects made five passes through each gate for each fabric specimen.

Two types of barbed wire damage were observed. One was surface snagging in which individual fibers or yarns were lifted out of the plane of the fabric in a manner similar to that observed in the case of bramble snagging. The second type of damage was much more severe and occurred when a deep penetration of the fabric by the barbed wire was not released as the test subject passed through the gates. As a result, the inertia of the moving body produced a large tear in the fabric.

Visual inspection of the chaps showed that the type and extent of surface snagging produced by the barbed wire was similar to that observed in the bramble snagging. The 8.2-ounce twill, which has high amplitude floats, and the filament rayon showed the greatest amount of surface snagging for the five fabrics tested.

On the other hand, the incidence of fabric tearing as a result of deep penetration of the barbed wire appeared to be more related to fabric thickness and flexibility. The thicker and less flexible fabrics were more resistant to catching and thus to tearing. Probably the ultimate tear resistance of the fabrics had an influence in this respect also.

The total number of times each test subject was caught on the barbed wire is shown in the following table:

TABLE II

NUMBER OF SNAGS RESULTING IN TEARS

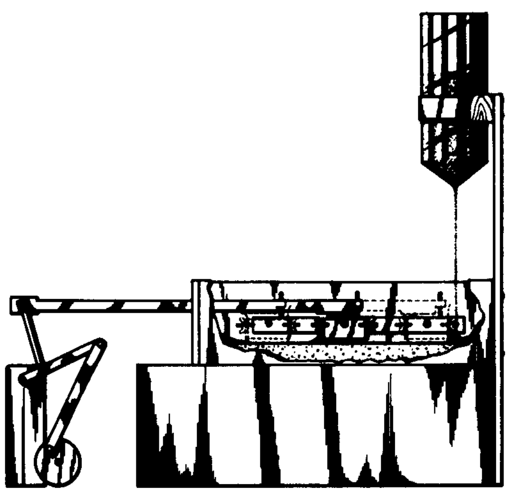
Fabric	Subject 1	Subject 2
8.2-oz combed cotton uniform twill (face)	4	6
5.0-oz rayon satin	4	5
8.8-oz carded cotton sateen (back)	1	1
6.0-oz cotton poplin	6	8
9.0-oz cotton oxford	0	6

This preliminary study sheds some light on the complex interrelationship between snagging and tearing. Apparently the depth of penetration of the snagging point into the fabric must be considered in conjunction with the degree to which the snagging point is capable of yielding under the applied tension. Even with rather deep penetration, if the snagging element yields at a load less than that required to tear the punctured fabric, then simple yarn and/or fiber snagging similar to that observed with brambles will occur. On the other hand, if the snagging element does not yield, then a tear may occur if the mechanics and dynamics of the fabric system favor the retention of the snagging element during the testing interval. Assessment of the data in Table II would indicate a marked snag advantage for the thicker, less deformable, and more highly tear-resistant sateen fabric.

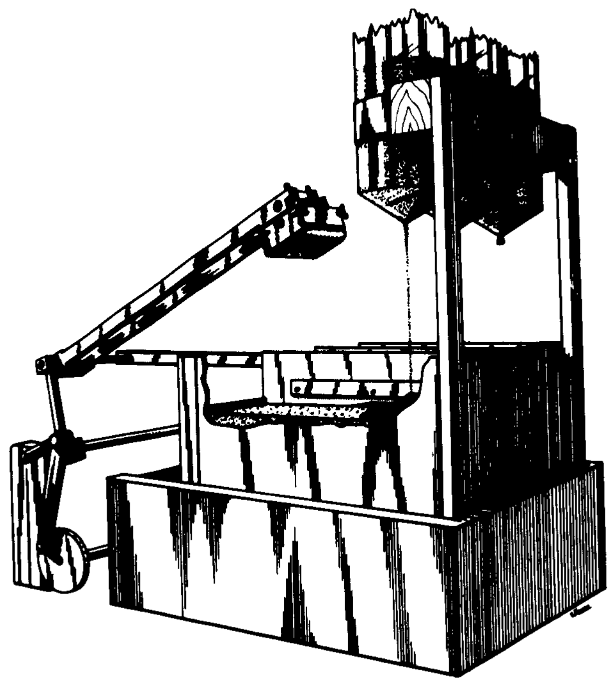
c. Sand Abrader

A typical characteristic of the accelerated wear course at the Army Field Evaluation Agency is the preponderance of sand that enters into the abrasive action at the various obstacles. In a sense, the type of wear produced may be characterized by the term "3-body wear" as used by Rabinowicz (5) to describe a system in which a loose abradant such as sand forms the abrasive medium between two other bodies, one or both of which will be subjected to wear. From the very first obstacle on the accelerated wear course, the garment is rubbed through sand that is also picked up by the fabric and carried on to the next obstacle. Regardless of the nature of the subsequent obstacles (wood, stone, concrete, or metal) a significant portion of the wear must be of the 3-body type in which the sand between the two bodies gouges out material from the softer of the two, which is the textile.

To take advantage of this phenomenon in a laboratory test, a special trough was designed into which sand can be fed at a relatively constant rate. A weighted moving arm on which samples are mounted rubs through the bed of sand at a constant speed until a visible hole is produced in the fabric. Diagrammatic sketches of the Sand Abrader are shown in Figure 3.



Side view, arm lowered



Oblique view, arm raised

Figure 3 - Sand Abrader

Preliminary studies conducted with the Sand Abrader have illustrated its versatility and high degree of correspondence to the fabric course. This became particularly evident in an evaluation of blended serge fabrics containing mixtures of 15 or 30 percent of man-made fibers in a matrix of 85 or 70 percent of wool. Table III illustrates the correlation obtained.

TABLE III

SAND ABRASION EVALUATION AND WOOL FABRIC COURSE DATA

Fabric	Fabric Course Rankings	Sand Abrader Rankings* 1	2	3	Avg.	Average Ranking
70/30 wool/nylon	1	1	1	1	1.0	1
70/30 wool/modacrylic	2	3	3	4	3.3	3
85/15 wool/modacrylic	3	4	5	3	4.0	4
70/20/10 wool/visc/nylon	4	2	2	2	2.0	2
70/30 wool/visc (3d)	5	5	4	5	4.7	5
70/30 wool/visc (5.5d)	6	6	6	6	6.0	6
85/15 wool/visc	7	7	7	7	7.0	7

* As judged by three observers.

As with many instruments of this type, the major difficulty in using the Sand Abrader is the problem of establishing a consistently valid end point. Generally, three samples are abraded simultaneously until a hole of significant size appears in one of the three. Comparisons of the appearance of the three fabrics with subsequent groups of three provides a more objective basis for subjective comparisons.

The excellent agreement between fabric course wear and laboratory sand abrasion has added credence to the belief that sand is the major element that produces wear on the accelerated course. If this assumption is correct, then the question arises as to whether normal combat wear involves the same dependence upon sand or granular material of similar composition. A correlation study reported in one of the latter sections of this report (p. 48) sheds some light on this problem.

d. Stoll-Flex Abrader

The Stoll-Flex Abrader has been used for many years as the standard method for evaluating the abrasion resistance of fabrics for combat use. Originally the merit of the Stoll machine was based on a correlation, established at the end of World War II, between the laboratory and field wear of a group of cotton fabrics in the fatigue fabric range. The flexing motion of the blade provided an action that was typical of field wear and that was not duplicated to the same extent in other types of abrasion instruments available at the time. The Stoll instrument proved quite valuable in demonstrating the low resistance of resin-treated fabrics that gave unrealistically high wear values on many of the other conventional abrasion testers.

However, the introduction of new fibers and blends and a variety of fabric finishes made certain weaknesses in the Stoll machine evident. For example, in nylon blends, particularly those containing a lubricating finish, the time required to reach an end point on the Stoll machine was excessive and made the use of the machine impractical. This problem may be solved by the use of the BFT Mark III Abrader, as described in the next section.

Because of the nature of the contact between the fabric and the Stoll-Flex blade, the abrasion levels recorded are extremely sensitive to the presence of any lubricants and many types of fabric finishes. By carefully cleaning the Stoll blade with Stoddard's solvent between tests and by evaluating fabrics which have supposedly been brought to equilibrium by successive launderings, it was thought that realistic abrasion levels could be determined. Recently it has been found that these procedures are not adequate for the purpose and many types of lubricating agents remain in the fabric after repeated launderings, leading to abnormally high cycles to rupture. Unfortunately, these lubricating agents do not necessarily result in an increase in wear as observed in the field, and thus the level of wear as measured on the Stoll machine is often unrealistic.

The marked influence of a lubricant on Stoll test results, even in fabrics considered to be essentially "unfinished", was demonstrated with production-run 8.8-oz carded sateens from five manufacturers. These fabrics were all woven from 13/1 warp and 10/1 filling yarns in a 5-harness sateen weave and a texture of 85 x 54. No finishing had been specified for them, however the use of textile auxiliaries in their scouring, dyeing, and sanforizing was not prohibited. Their flex abrasion resistance (using blade 396 on a model CS-39 Stoll Abrasion tester, 1 lb of pressure, and 4 lb of tension) was evaluated before and after chloroform extraction. The results, found in Table IV, show a wide variation in the before-extraction results and markedly reduced but generally more uniform results after chloroform extraction.

TABLE IV

FLEX ABRASION RESISTANCE OF CARDED SATEENS BEFORE AND AFTER CHLOROFORM EXTRACTION
(warp direction and on filling flush surface)

Sample Number	Before Extraction (in cycles to rupture)	After Extraction (in cycles to rupture)
1	2120	390
2	850	390
3	2530	510
4	3240	390
5	2110	460
6	2390	430
7	4200	660

Another problem with the Stoll-Flex Abrader appears to be associated with the high temperatures arising at the fabric-blade interface. It is difficult to measure this temperature although, as indicated later on, attempts have been made to do so. The reason for suspecting temperature sensitivity is that blends with modacrylic fibers show relatively good performance in accelerated field wear and in the Sand Abrader yet relatively poor resistance on the Stoll machine. The performance of blended serges, as ranked on the Stoll Abrader, in the Sand Abrader, and on the Wool Fabric Wear Course (Table V) shows closer agreement between the Sand Abrader and Wool Course than between the Stoll Abrader and Wool Course.

TABLE V

RELATIVE RANKINGS OF BLENDED SERGES

Blend	Wool Fabric Course (x)	Stoll Abrader (y)	|x-y|	Sand Abrader (z)	|x-z|
70/30 wool/nylon	1	1	0	1	0
70/30 wool/modacrylic	2	4	2	3	1
85/15 wool/modacrylic	3	7	4	4	1
70/20/10 wool/visc/nylon	4	2	2	2	2
70/30 wool/3-d visc	5	3	2	5	0
70/30 wool/5.5-d visc	6	6	0	6	0
85/15 wool/visc	7	5	2	7	0

It is hoped that studies correlating wear on the Wool Fabric Course with actual wear in the field will further validate the usefulness of the Sand Abrader. However, until further information can be obtained on the significance of the above observations, all samples are tested on the Stoll machine in the chloroform-extracted as well as in the original condition. Nevertheless, increased reliance is being placed on the Sand Abrader, and programs are planned to determine the significance of the various testing parameters and to evolve an objective end point for this instrument.

e. BFT Mark III Abrader

Some of the cotton/nylon blends developed for thermal protection require as many as 80,000 cycles to rupture when tested on the Stoll-Flex Abrader. Since the speed of the Stoll machine is approximately 120 cycles per minute, it would take approximately 660 minutes or 11 hours to rupture a specimen of this type. Attempts to reduce this time requirement by using narrower samples were not successful because unwanted inertial disturbances were produced which increased the variability in the test data.

The Bocking Laboratory of Courtaulds Ltd. has developed the BFT Mark III flex abrasion tester, modeled on the Stoll machine, which eliminates some of the problems encountered in the Stoll. Its two most important innovations are 1) the elimination of a significant portion of the inertial forces characteristic of the Stoll, and 2) an increase in the frequency of the moveable stage to reduce the time requirement for an individual test. Limitations in the use of the British machine arise from the fact that it is equipped with two blades representing two frictional extremes: one with a rounded edge, which is too mild; and the other with a square edge, which is much too severe for even the long-wearing cotton/nylon blends. To eliminate this difficulty and, at the same time, to obtain a type of abrasive action which more closely approximates that of the Stoll machine, the square-edge blade has been fitted with a carbide steel edging of the same type conventionally used in the Stoll machine.

Tests on the BFT Mark III Abrader were carried out in accordance with the procedure issued by the manufacturer in August 1956 (6). Briefly, a 1-inch strip of fabric was flexed around the carbide edge of the flexing plate, with a 2-pound dead weight on the stirrup tension spigot and a 4-pound head weight. The carriage, to which one end of the specimen was attached, has a stroke of 1/2-inch and reciprocates at 700 RPM. At break, the tension on the stirrup chain is released and the weight load dropped, activating a micro-switch which stops the motor. The carbide edge of the flex blade had previously been subjected to 30,000 strokes against a 10-oz duck, in accordance with the procedure recommended for the Stoll machine. Data obtained on samples from a Nyco* series of fabrics (Table VI) show that the BFT Mark III Abrader also exhibits sensitivity to lubricants or finishes.

The BFT Mark III and Stoll Flex Abraders were both used to evaluate a group of 9 samples having a wide range of abrasion resistance and to indicate the degree of correlation between the two instruments and the variability associated with each. The results shown in Table VII and the rankings plotted in Figure 4 demonstrate the extent of agreement between the two instruments. The Spearman's rank difference coefficient of correlation was computed to be 0.8.

* Nyco - an optimally engineered cotton/nylon blend designed for thermal protection.

TABLE VI

FLEX ABRASION (CYCLES TO RUPTURE) OF SATEENS ON THE BFT MARK III TESTER (warp-back testing)

	Carded Cotton	50/50 Cotton/Nylon	Cotton Warp Nylon Fill	50/50 Cotton/Nylon (heavy wt)	50/50 Cotton/Nylon Quarpel-tr. (heavy wt.)*
			Unextracted		
	810	5420	2240	9360	20140
	1210	5120	2160	11300	38370
	1450	5000	2780	6520	
	860	7110	3750	7520	
	940	3770	4490	8410	
Rounded Average	1050	5280	3080	8620	
			Chloroform Extracted		
	590	1630	1470	3040	
	850	2210	2630	1910	
	690	1710	1590	2050	
	660	1440	1820	3120	
	680	2190	1380	1790	
Rounded Average	690	1830	1780	2380	

*Only two specimens of this fabric were tested because of the large number of cycles required to rupture.

TABLE VII

FLEX ABRASION (CYCLES TO RUPTURE) ON STOLL AND BFT MARK III TESTERS (warp direction & filling flush surface)

Fabric	Stoll Avg.($\bar{X}$)	Stoll Range/$\bar{X}$	BFT Mark III Avg.($\bar{X}$)	BFT Mark III Range/$\bar{X}$	Relative Rankings Stoll	Relative Rankings BFT Mark III
Cotton/nylon	33460*	-	6240*	-	1	1
Cotton/nylon (ext)	11820	1.19	1700	.24	2	3
Modacrylic	860	.12	700	.18	7	6
Modacrylic (ext)	1620	.87	250	1.16	5	9
Cotton EP	3880	.37	1860	.37	3	2
Cotton EP (ext)	660	.85	540	.31	9	7
Cotton A	1030	.37	920	.57	6	5
Cotton WP (ext)	780	.88	530	.51	8	8
Cotton R	1750	.43	970	.24	4	4

*Only one specimen was used; five specimens for all other averages.

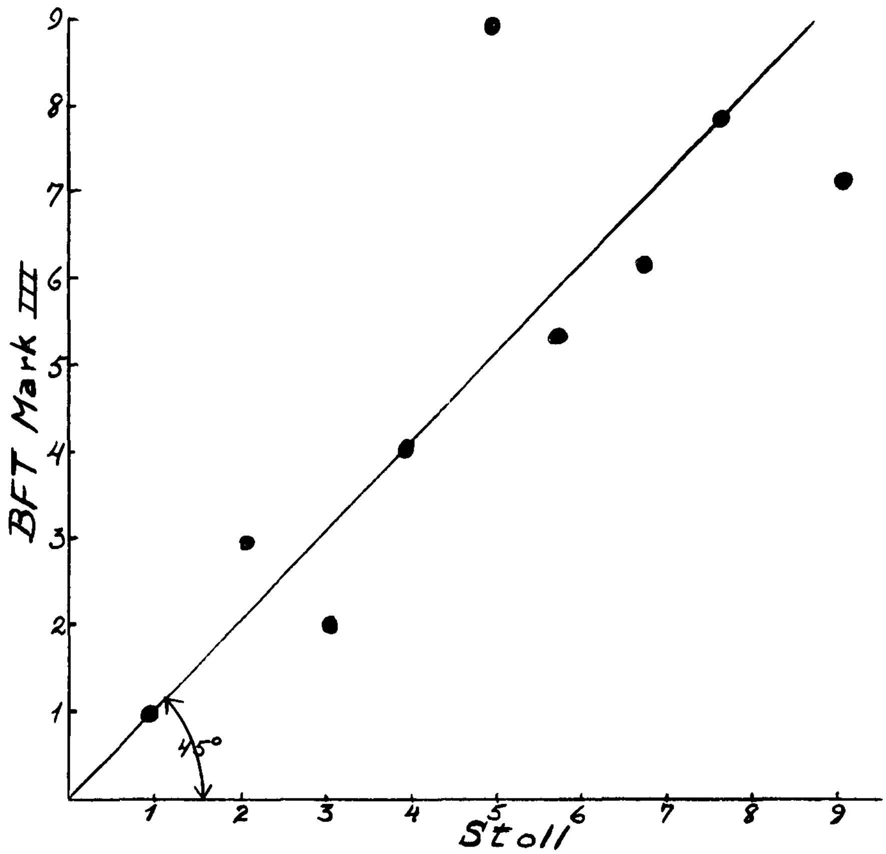


Figure 4 - Rank correlation of Stoll and BFT Mark III testers

The Range/$\bar{X}$ ratios were lower for most of the fabrics evaluated on the BFT Mark III Abrader. However, for three fabrics this trend was reversed. Additional studies will probably have to be conducted to determine the exact level of difference in variability between the two machines. In general, the Stoll tests showed more "within sample" variation among the extracted samples (ext), as indicated by the Range/$\bar{X}$ ratio, than among the unextracted samples. This difference was not obvious for the samples evaluated on the BFT Mark III tester. The major advantage of the BFT machine appears to be that it reaches an end point more rapidly. This is particularly evident for the two cotton/nylon samples, which took up to 5 hours of machine-running time to reach an end point on the Stoll whereas they took only 9 minutes on the BFT machine.

f. Wear Score Systems

At the time of the development and construction of the accelerated wear course at Fort Lee, Virginia, during World War II, the U. S. Quartermaster Board (USQMB), later called the Field Evaluation Agency (FEA), devised a scoring system to measure the degree of wear observed on the garments after each cycle of wear (two traversals of the course). Although records of the original concepts that were used to arrive at this scoring system are not available, it is assumed that the system was based upon judgement evaluations of the types and degrees of failure that are likely to make a garment unserviceable for combat use. In recent years, work has been carried out in England to derive a new wear-score system which would be based upon evaluations made by qualified sorters of the suitability of garments for operational use. This approach is quite valid since it is essential that a scoring system in which confidence may be placed should reflect both the types and the degrees of failures observed in operational wear.

In the FEA scoring system, four types of failure are evaluated: holes, tears in wear areas, frays, and wear areas. An arbitrary number, designated as "degree of failure", and based upon a unit of measurement, is assigned to each of these types of failure. The lengths of tears and frays and diameters of holes are measured in inches; the areas of wear are measured in square inches. To increasing class intervals for each type of failure, a degree of from 1 to 6 inclusive is assigned. Point values are arbitrarily assigned to each degree and type of failure. The total point values for a particular garment constitutes its wear score. For purposes of evaluating the serviceability of fabrics, instances of accidental tear and stitching, bar tacking, and button failures are not scored.

The original scoring system used in England was similar in many respects to that of the FEA. However, no distinction was made between different degrees of "wear area", slightly different score levels were assigned to equivalent degrees of "holes" and "tears", and the different degrees of "fray" were described quantitatively. A tabular comparison of the original British system and that of FEA is given in Table VIII.

Dissatisfaction has been expressed (7, 8) with both systems because of the excessive weightings given small holes and the problems in "individual assessment of minor failures occurring in close proximity".

In recent years, the British have favored a scoring system in which the sum of the length of tears, the sum of the length of frays, and the sum of the areas of the holes would be used as respective measures of each of the categories of wear. Wear areas would be ignored completely. The advantage of this system in simplicity and in

TABLE VIII

PRESENT WEAR SCORE SYSTEMS

Category	Degree	British (original method) Description	British (original method) Score	United States Field Evaluation Agency Measurement	United States Field Evaluation Agency Score
Fray	1	First visual sign of wear	0	≤1 in	0.5
	2	Signs of wear more noticeable	0	> 1 in ≤ 3 in	1
	3	Threads distinctly visible	5	> 3 in ≤ 6 in	2
	4	Threadbare condition at point of wear	5	> 6 in ≤ 10 in	3
	5	Any break in threads at point of wear	10	>10 in ≤15 in	4
	6	---		>15 in	5
Hole	1	≤ $\frac{1}{4}$ in	5	≤ $\frac{1}{4}$ in	5
	2	> $\frac{1}{4}$ in ≤ $\frac{1}{2}$ in	5	> $\frac{1}{4}$ in ≤ $\frac{1}{2}$ in	9
	3	> $\frac{1}{2}$ in ≤1 in	10	> $\frac{1}{2}$ in ≤ 1 in	11
	4	>1 in ≤ $1\frac{1}{2}$ in	15	> 1 in ≤ $1\frac{1}{2}$ in	13
	5	> $1\frac{1}{2}$ in ≤2 in	15	> $1\frac{1}{2}$ in ≤ 2 in	14
	6	>2 in	20	> 2 in	15
Tear	1	≤1 in	5	≤ 1 in	5
	2	>1 in ≤2 in	5	> 1 in ≤ 2 in	9
	3	>2 in ≤3 in	10	> 2 in ≤ 3 in	11
	4	>3 in ≤5 in	15	> 3 in ≤ 5 in	13
	5	>5 in ≤7 in	20	> 5 in ≤ 7 in	14
	6	---		> 7 in	15
Wear Area	1			≤ 4 sq in	4
	2			> 4 sq in ≤ 9 sq in	6
	3	No distinction made		> 9 sq in ≤ 16 sq in	9
	4	between degrees of	15	>16 sq in ≤ 25 sq in	11
	5	wear		>25 sq in ≤ 36 sq in	13
	6			>36 sq in	15

eliminating the problem of assigning excessive weight to small holes is obvious. However, the problem of assigning a meaningful weighting to each of the categories of wear still remains. Greenland and Reid (9) have developed a comprehensive weighting system that may meet this problem.

The procedure developed by Greenland and Reid is based on the technique of discriminant analysis, in which the judgement of skilled observers as to the serviceability or lack of serviceability of a series of garments is compared to an objective scoring based upon such parameters as hole area and length of tears. In Figure 5 for example, is a reproduction of a plot from Greenland and Reid's paper in which the square root of hole area is plotted against total tear length for a group of garments which had been rated as unserviceable (crosses) and serviceable (dots) by an expert classifier.

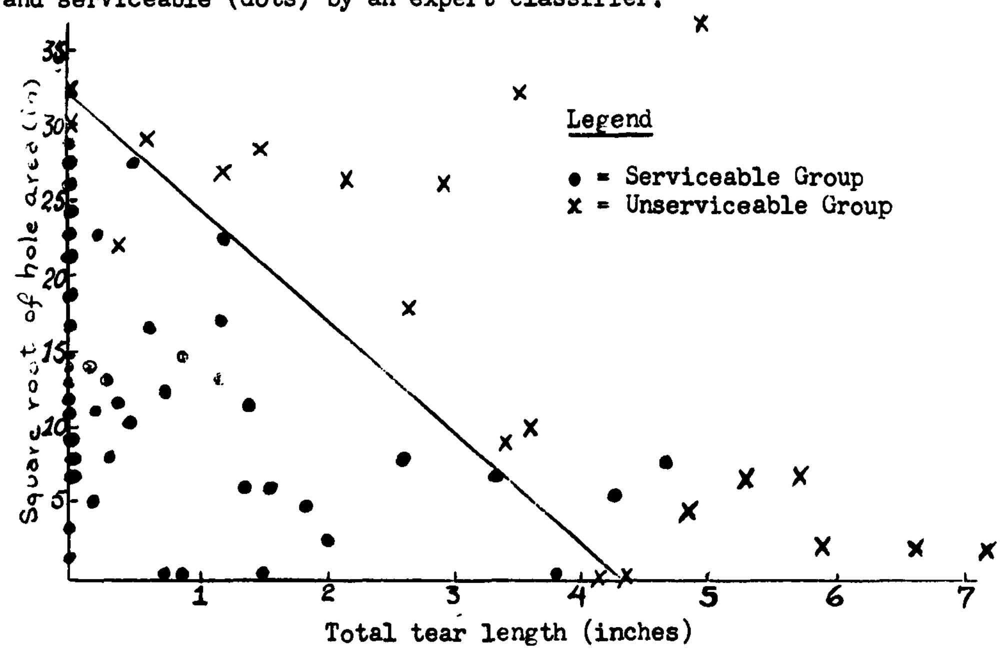


Figure 5 - Relationship between square root of hole area and total tear length

The equation of that straight line which best discriminates between the two groups of garments, and the slope of the line, may be used as the basis for a more realistic scoring system. For a given garment the wear score may be obtained from the equation:

$$W.S. = \sqrt{H} + \lambda T$$

WHERE:

W.S. = wear score
$\sqrt{H}$ = square root of hole area
T = tear length
λ = slope of line

For the particular set of data in Figure 5, λ is equal to 7.12. To determine the exact value of λ, data obtained from many observers must be used.

Dr. George P. Wadsworth of the Mathematics Department of M.I.T. has suggested that the development of a scoring system could be approached more simply by the use of a linear scale technique in which wear scores ranging from the lowest to the highest would be plotted. As with the discriminant analysis technique, separate plot marks as determined by the classifiers would be used for each of the groups. After a significant amount of data has been obtained, the point of discrimination along the wear score line of the different groups would be determined on the basis of minimizing the overlap per group.

g. Normality of Wear Score Data

To facilitate the analysis and interpretation of data from combat course testing, it would be desirable to have the wear scores distributed normally so that conventional statistical techniques can be used with greater confidence. Quite often, however, the data diverge from the normal to such an extent that serious questions are raised as to the validity of the conclusions. An analysis was made of the wear scores obtained in an engineering test of the wear resistance of a cotton/nylon fabric (65/35 blend) to characterize the nature of the distribution of the wear scores, to analyze the distribution in terms of the test subjects involved, and to suggest ways of obtaining better distributions.

This test was conducted in two separate phases, using 32 medium-size test subjects for each phase. In the first phase, the subjects were instructed as to the proper manner of traversing the course. When the test subjects became familiar with the course, the number of traversals was increased, during a 14-day period, until the men were able to make a minimum of six traversals a day. Twenty of these subjects were selected to test trousers made from experimental and standard fabrics. Presumably, the selection was based upon the expectation of a relative homogeneity in test scores. The second phase was organized and carried out exactly as the first phase. Only 17 of the 20 test subjects selected completed the first phase, while 19 completed the second phase. Average wear scores for each phase of the test are given in Table IX.

These data show that the average wear scores were significantly different in the two phases of the test. While in both phases the scores for the cotton/nylon trousers worn warp side out were significantly higher than those for the other trousers, there was no significant difference between the cotton/nylon trousers worn filling side out and the standard.

TABLE IX

AVERAGE CUMULATIVE WEAR SCORES BY TRAVERSALS OF THE COMBAT COURSE

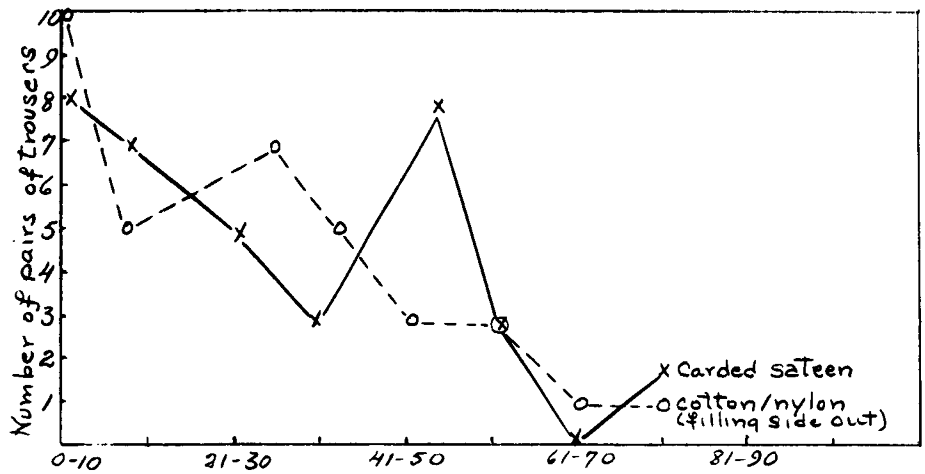
Fabric	Phase	Average Wear Scores After Traversals									
		2	4	6	8	10	12	14	16	18	20
Cloth, cotton/nylon (65/35 blend), 8.2-oz, warp side out	I	2.9	8.7	12.4	22.0	28.2	34.5	40.5	45.1	47.4	52.5
	II	3.4	5.0	6.6	10.2	14.3	17.8	23.7	28.1	32.1	35.0
Cloth, cotton/nylon (65/35 blend), 8.2-oz, filling side out	I	2.3	4.6	6.2	14.4	18.7	24.5	31.0	34.3	35.9	38.5
	II	1.8	3.2	3.7	5.3	7.1	9.0	11.0	12.6	15.0	20.2
Cloth, cotton carded sateen, 8.5-oz (standard)	I	2.6	7.5	9.6	14.0	17.2	22.7	26.2	29.7	31.7	36.2
	II	1.6	3.4	4.7	6.3	9.5	13.6	17.8	20.7	22.2	25.0

Note: Standard error of the mean at the end of 20 traversals = 2.24

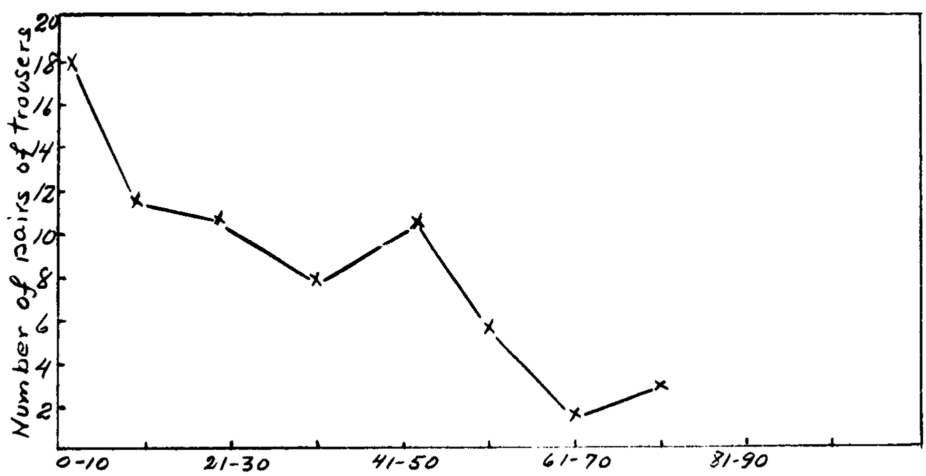
Since the average wear scores cited in Table IX give no indication of their distribution by test subjects, an analysis was made of the individual tally sheets used by the scorers. These sheets showed that the predominant cause of trouser failure was hole formation. A few wear areas were noted, but there was no mention of tears or frays. The tally sheets also showed that an exceptionally large number of trousers had low wear scores, indicating little or no damage. On the other hand, relatively few trousers had scores that would indicate heavy damage. The slopes of the distribution of the wear scores as shown in Figure 6 appear somewhat hyperbolic. Figure 6a shows the distributions for the 8.5-oz standard and the 8.2-oz cotton/nylon fabrics, considered individually; Figure 6b shows the combined distribution.

It is evident that there must be an association between the trousers that exhibited high and low wear scores and the corresponding test subjects. A rank correlation analysis of the wear scores obtained by the test subjects wearing high and low-wear-scoring trousers yielded a rank correlation coefficient of .70, clearly showing that an association does exist.

It was observed that the experienced subjects were able to maneuver the most difficult obstacles with the expenditure of relatively little energy, despite the fact that during the indoctrination period energy expenditures were high and resulted in more wear and tear on the individual and, conceivably, on the garment itself. This suggests that, during the course of testing, the damage rate to the garments may decrease rapidly as the test subjects become more experienced. This is not a deliberate attempt on the part of the test subjects to avoid wear on the garments but



a. Sateen and cotton/nylon blends



b. Combined fabrics

Figure 6.- Wear score distribution

represents a natural tendency to minimize skin abrasion and fatigue. There appears to be a way to get around this dilemma. Since many of the obstacles that probably required the greatest expenditure of energy did not produce the greatest amount of wear on the trousers, whereas other obstacles that probably required the expenditure of little energy produced considerable wear, substitution or modification of these obstacles would tend to change the amount of wear on the garments and would probably bring the distribution of wear scores closer to normal.

An alternative approach to this problem would involve running the individual garments in the test to a constant wear score instead of for a constant number of cycles. By this procedure, every garment in the test would sustain a significant amount of wear and the number of traversals required to produce this level of wear would represent the score. Thus, the averaging in of wear scores on items which have not sustained any significant wear would be eliminated. Such an approach has its disadvantages. It is difficult to administer because those individuals who produce wear at a very slow rate would have to be kept in the test much longer than the others and the temptation to induce premature failure of the item would increase. In addition, the overall average time to complete a test would increase to a point where it would not be feasible in terms of schedules and commitments. On the other hand, if a large enough population of test subjects were available, it would be possible to select a group that would be much more homogeneous in its wear pattern and, with very large groups, it is conceivable that a modal group could be obtained that would provide a normal distribution. However, in terms of extrapolation to the general population, data obtained from a group such as this might be more difficult to analyze.

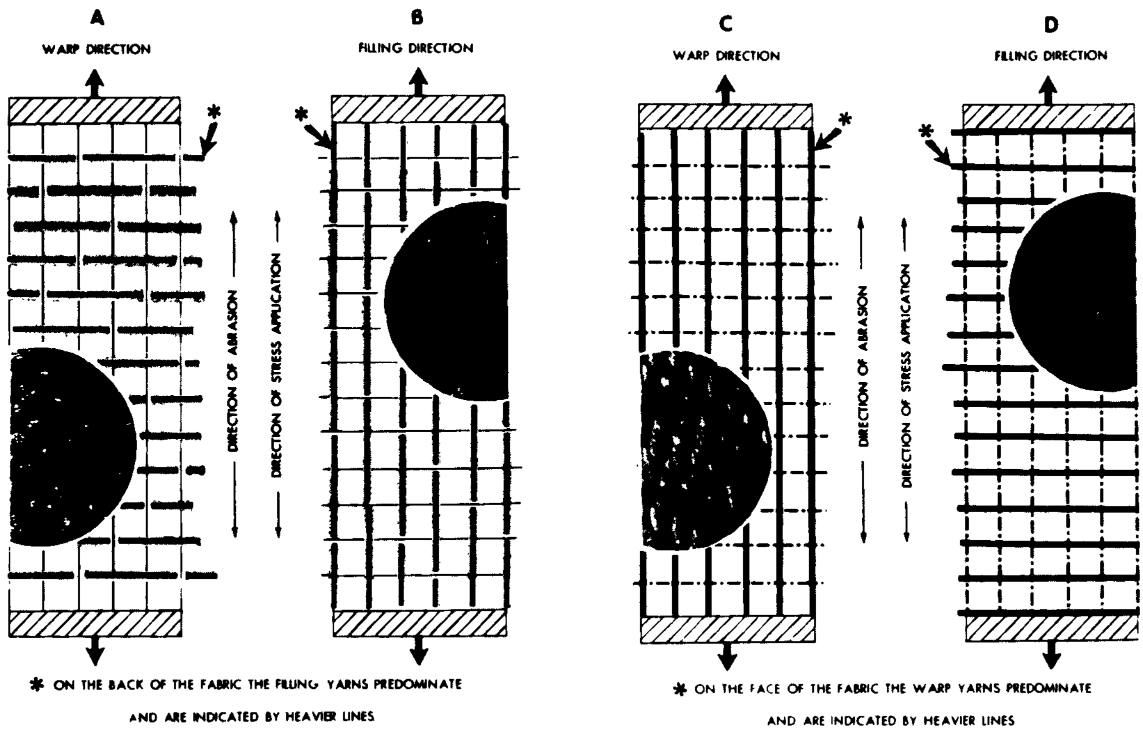
3. Wear Mechanisms

a. Directional Effects in the Sateen Weave

Studies of fabric characteristics that influence abrasion resistance have led to certain generalizations concerning the effect of weave. In 1946, Kaswell (10) observed that "Fabrics abraded in different directions have the same abrasion-resistance rank when tested in a single direction; fabrics abraded in a single direction show inverse abrasion resistance when tested in perpendicular directions. The sateen back when abraded and tested warpwise, and the twill face when abraded and tested fillingwise, are the most abrasion-resisting surfaces." Morton (11) found that if abrasion and stress occur in opposite directions, maximum wear will take place when the non-stress-bearing yarns are presented to the rubbing surface with their floats running in the direction of rubbing. Backer (12) mentions that advantage can be taken of this property by exposing either the face or the back of the material to the rubbing element, depending upon which side exposes the non-stressed yarns.

The U. S. Army Natick Laboratories have applied these findings in their 8.5-oz carded sateen, which is now always worn with the filling flush side (back) of the fabric to the outside. In this system, the non-stress-bearing (filling) yarns are subjected to wear before the stress-bearing (warp) yarns.

Some recent tests have shown rather good agreement between warp direction abrasion on the back of a sateen and filling direction abrasion on the face, and conversely between warp direction abrasion on the face and filling direction abrasion on the back. The accompanying sketches (Figure 7) illustrate the location of the yarn systems with respect to the direction of abrasion, the relative positions of the stress-bearing yarn systems, and the yarn direction that is subjected to the initial abrasive action. On the extreme left (A), the fabric is shown with the back (filling flush) side to the abradant. The filling yarns are perpendicular to the direction of abrasion, whereas the warp yarns, which are the stress-bearing yarns in this particular system, are parallel to the direction of abrasion. Because of the nature of the sateen weave, the filling yarns occupy a raised position on the back of the fabric, hence will be abraded first. During the course of a test using the Stoll-Flex Abrader (13) with 4 pounds of tension applied to the stress-bearing warp yarns, the fibers from the filling yarns were broken first and rolled into a small cylindrical mass that had to be periodically removed from the field of the abradant action. Then the warp yarns began to appear through the filling yarn mass and, as shown in Figure 8, it was possible to abrade away practically all of the filling yarns and still leave the stress-bearing warp yarns relatively intact. As the test continued, the warp yarns began to be abraded and then they too ruptured. Thus, it appears that the total abrasion resistance to rupture was equal to that of the filling yarns plus that of the warp yarns up to the point at which the strength of the warp yarns had been decreased to 4 pounds, which was the applied tension.



Back of Fabric

Face of Fabric

Figure 7 - Directional effect of sateen weave on abrasion resistance

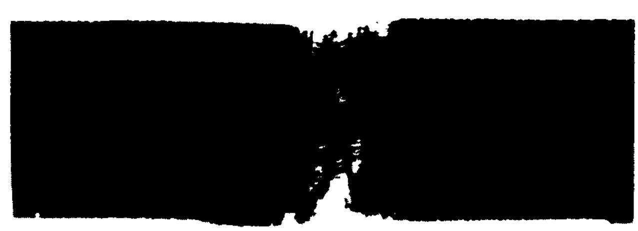


Figure 8 - Warp direction abrasion on the back of a cotton sateen

In Figure 7B, the direction of abrasion is 90 degrees to that in A. The filling yarns again failed first and formed a similar small cylindrical mass of broken fibers. As the abrasive action continued and the filling yarns were destroyed, the warp yarns came into play to contribute additional wear. However, since in this case the filling yarns were the stress-bearing yarns, the warp yarns could contribute nothing to support the tension and, accordingly, when the filling yarns were abraded to the point where the strength of the filling yarns had dropped to 4 pounds, the specimen ruptured. Thus, abrasion resistance in the filling direction on the back side of the fabric is contributed to only by the filling yarns themselves, with the possible addition of the few interlacings of warp which appear on the back of the fabric. The difference between warp and filling direction abrasion on the back of the sateens may range from approximately 300 to 1,000 cycles, depending upon the particular fabric being tested. The same reasoning is applicable to abrasion on the face of the fabric (Figure 7 C and D).

The close agreement between face-warp and back-filling abrasion and between face-filling and back-warp abrasion is noteworthy (Table X). The numerical differences between the warp and filling direction abrasion on the back and face respectively also show rather good agreement. This would lead to the conclusion that each yarn system acts somewhat independently of the other. Furthermore, complete participation by both yarn systems can be obtained only when the stress-bearing yarn system is "buried". The simplicity of this principle suggests the possibility of predicting the abrasion resistance of a homogeneous group of materials in terms of parameters that may be closely related to the strength and mass of the stress-bearing yarn system and the mass of the orthogonal system, which must literally be worn away before the stress-bearing yarns can be brought into play to sustain the applied load. One may conclude that the proper placement of yarns to cover and support the stress-bearing yarn system could lead to significantly improved wear resistance of fabrics.

b. Frictional Heat

Studies (12) conducted during the post-World War II period have emphasized the importance of friction in the flex abrasion resistance of textile fabrics. The wear producing potentialities of friction have been considered under two categories: mechanical and thermal. Mechanical effects become manifest in a "ploughing" of a soft surface by the asperities of a harder one, or by a shearing of junctions formed by the strong adhesion between the substance being abraded and the abradant. Thermal effects are probably more significant for thermoplastic fibers, in which alteration in the local stress-strain properties occurs as a result of an increase in temperature.

TABLE X

COMPARISON OF WARP AND FILLING DIRECTION ABRASION RESULTS (CYCLES)

Sample No.	Warp	Filling	Difference
		Back	
1	890	630	+260
2	1530	930	+600
3	2160	1200	+960
4	970	670	+300
		Face	
1	530	810	-280
2	1000	1610	-610
3	1480	2220	-740
4	660	910	-250

The mechanical breakdown of textiles during abrasion has been attributed to cutting of fibers, snagging of fibers, and frictional wear. The mechanical and thermal influences which occur simultaneously during flex abrasion should be capable of being related to friction. It is difficult to measure mechanical effects because of the limitations of instrumentation, but thermal factors can be approached indirectly through the use of thermocouple techniques.

Blades for the flex element of the Stoll Abrader are approximately 1.2 cm wide and 10.5 cm long (exclusive of mounting clips). Inserted along one edge of the blade (the portion along which abrasion occurs) is a carbide steel strip approximately 0.3 cm wide and 9.0 cm long. In an attempt to measure the heat of friction, a copper-constantan thermocouple was inserted into a hole drilled into the center of the back edge of blade No. 208 so that the juncture reached a point approximately 0.2 cm from the carbide steel strip, or 0.5 cm from the front edge of the blade (Figure 9). Because of the hardness of the carbide steel, it was not possible to drill beyond this point, thus the temperatures measured represented the temperatures at a point 0.5 cm from the fabric-blade interface. The thermocouple leads were connected to a Leeds & Northrup potentiometer and readings were taken at the beginning of the test and after intervals of 50 or 100 cycles. Two fabrios were used, a 50/50 cotton/nylon sateen and a wool broadcloth weighing 10.5 oz. The data obtained are shown in Table XI.

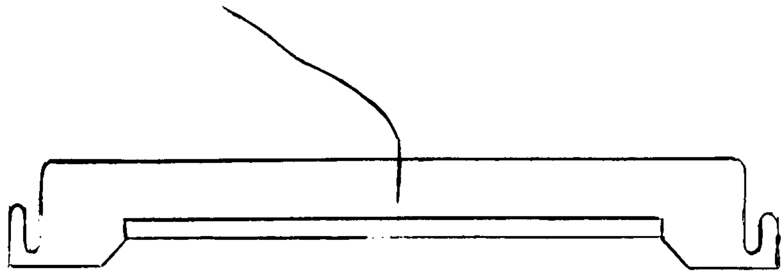


Figure 9 - Sketch of X-ray of flex blade showing location of thermocouple

TABLE XI

TEMPERATURES OBSERVED DURING ABRASION

Fabric	Cycles of Abrasion 0	50	100	200	300	Completion of test
Cotton/nylon sateen (°F)	80	--	90	90	90	80 (688 cycles)
Wool broadcloth (°F)	82	88	89	89	--	82 (500 cycles)

It will be noted that temperatures rose rapidly upon initiation of abrasion but at the end they leveled off at a constant value. Upon curtailment of abrasion, the temperatures dropped rapidly to their initial values. Even though the tests were conducted in a room conditioned to a temperature of 70°F, starting and finishing temperatures were well above this value. The abrasion machine itself acted as a heat sink and conducted the higher motor temperature to the thermocouple juncture. The rapid diffusion of heat to the thermocouple during abrasion indicates that the boundary temperatures were quite high. Howell, Miezkis, and Tabor (14) have pointed out that "The greater part of the work expended in overcoming friction is liberated as heat; often the amount of heat is very small. However, because the area of contact is generally so minute and the heat is generated precisely at these points of contact, the local temperature rise may be very large indeed." Since non-metals are usually poor conductors of heat, they may sustain high surface temperatures more readily than metals. Experimental data are lacking on surface temperatures reached in metal/fiber friction, but the bulk of experimental evidence indicates that the temperatures are probably sufficiently high to alter the stress-strain properties of thermoplastic fibers and to lead to premature failure in abrasion testing.

In a subsequent study of frictional heat, the upper surface of the flex blade was grooved with a diamond tool perpendicular to its long axis and including the carbide steel edging. A copper-constantan thermocouple was soldered into this groove so that the junction was flush with the leading edge of the blade. Despite the difference in location of the thermocouple junction in the two experiments, the temperature rise was almost identical for each. It is probable that the groove necessary to place the thermocouple distorted the heat flow that would be expected when a completely solid metal is used. Probably the closer that one approaches the surface, the greater this distortion becomes. Considerable information of value could be obtained on this matter if more sensitive measurement techniques were available. The increasing use of low-softening-point man-made fibers, either alone or in blends with other fibers, adds an urgency to the need for determining the effect on the wear life of fabrics of temperature rise due to abrasion.

c. Surface Friction and Lubrication

Theories of adhesive and abrasive wear that have been formulated for metals are finding widespread application in the current technology of wear and abrasion phenomena. While these theories in their present form are not directly applicable to textile problems, they do shed light on some of the performance parameters that have been observed for textiles and probably, with some modification, they will prove to be quite useful.

The first theory, that of adhesive wear, is based almost entirely on current theories of friction and boundary lubrication. It states that, when metals are placed in contact, junctions are formed which, though small in number, are great in strength. As one surface moves with respect to the other, these junctions are sheared. If the shearing takes place within the junction rather than at the interface, a wear particle is formed. The volume of material sheared per unit length of abraded surface is formulated as:

$$V = K_m \left(\frac{f - f_1}{f_m - f_1} \right)^{3/2} \frac{L}{3p}$$

where f is the observed coefficient of friction,
f_1 is the coefficient of friction of a perfectly lubricated material,
f_m is the coefficient of friction of an unlubricated material,
K_m is a constant of proportionality related to the probability of a wear particle being formed,
L is the applied load,
3 is a constant related to the assumed shape of the wear fragment,
p is the penetration hardness of the material.

The above equation appears to be fairly consistent with observations that have been made on the Stoll-Flex Abrader, which is particularly sensitive to the presence of oils or lubricants of any kind. A lubricant placed on the fabric markedly reduces the coefficient of friction and thus the volume of wear is correspondingly reduced. With respect to the load, L, it is a common observation on the Stoll machine that the rate of wear is a function of the applied load and that increases in load produce corresponding increases in wear, although some of the data suggest that V may vary as a function of L^2 rather than of L.

When considering the significance of the p factor in the volume-of-material-sheared formula, textiles pose somewhat of a problem. While it is conceivable that in the abrasion of large monofilaments of visco-elastic fibers the relative hardness of the material would influence the volume of wear, it is difficult to measure this influence, although some efforts are being made to do so. It appears that the work-to-rupture of the fibrous substance of textiles is the controlling factor in their rate of wear. Whether this should be considered as part of the probability constant K_m or as a separate variable in the equation in lieu of the penetration factor remains to be determined. At any rate, the strong influence of the coefficient of friction on the phenomenon of adhesive wear suggests that this is a major factor in explaining the behavior of textile fabrics abraded on the Stoll machine.

While no actual friction measurements of fabrics have been made that can be compared with Stoll abrasion data, a significant relationship has been found between the cycles of chloroform extraction of a Quarpel-finished fabric and the Stoll flex-abrasion results of the same fabric. This is shown in Figure 10.

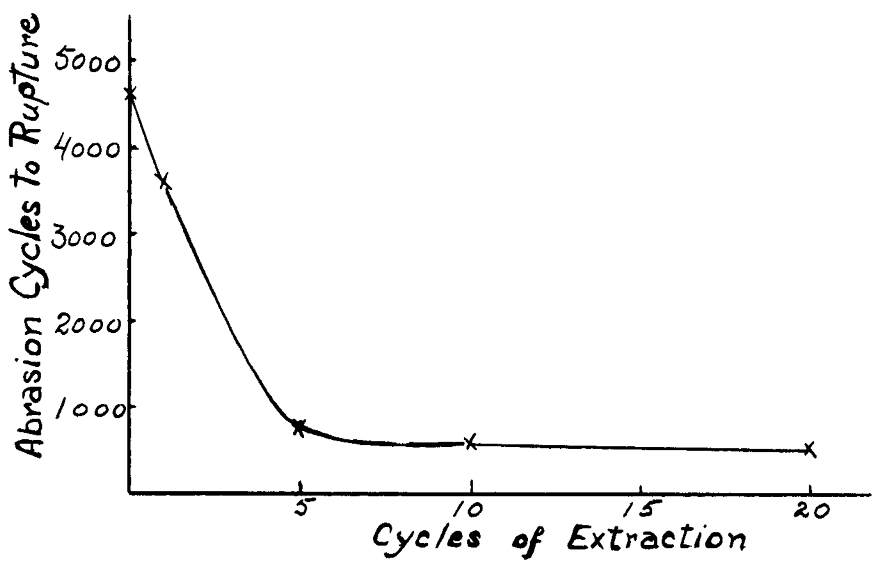


Figure 10 - Variation in flex abrasion resistance with cycles of chloroform extraction

The influence of lubricants should be carefully considered in all studies conducted on the Stoll abrader. In fact, it would appear desirable that studies of the influence of lubricants on fabrics be conducted using all of the currently available abrasion testers. This may be particularly important since it appears from the data that accelerated field wear and normal wear probably are not influenced at all by the presence of lubricants, or at most are only slightly influenced, and that the type of wear encountered in these situations may be better explained by a second theory, that of abrasive wear.

The theory of abrasive wear states that, when a hard surface or particle is pressed against a softer one and is moved, a portion of the softer material is gouged out. Abrasive wear may be of the 2-body type (in which a hard surface is in contact with a soft surface) or of the 3-body type (in which particulate matter or work-hardened, loose fragments are abraded between two sliding surfaces). In general, the equation for abrasive wear is similar to that for adhesive wear. The volume of worn material per unit length is equal to a proportionality factor multiplied by the load and divided by the penetration hardness, thus:

$$V = \frac{L\ (\mathrm{Cot}\ \theta)}{\pi p}$$

Cot θ/π represents the proportionality factor derived from the assumed shape of the abradant particle. This proportionality factor is independent of the surface friction since the indenter (e.g., sand or metal) penetrates beneath the surface of the medium being abraded and gouges out the material. It is assumed from previous data that the type of wear obtained on the accelerated wear course, and indeed on the Sand Abrader described on page 7 of this report, is of the abrasive type and is probably independent of surface friction effects.

Some workers have introduced into the abrasive wear equation another factor in which the wear resistance is affected by the amount of elastic deformation that the softer metal can undergo in attempting to avoid abrasion. In most textile applications, the rate of wear is inversely related to the weighted work-to-rupture of the component materials. Thus, abrasive wear should be proportional to $1/Wp$ or a power function of these factors.

d. Fiber and Yarn Morphology

Studies (15-18) made on single-fiber fabrics indicate that abrasion produces a weakening of fibers that is reflected in the development of cracks in the fiber surface, fibrillation, bruising, disappearance of scales (in the case of wool), and actual breaking of the fibers. These morphological changes are responsible for loss of strength of the individual fibers and a decrease in chain length of the fiber molecule which, in the case of cellulosic fibers, is attended by an increase in cuprammonium fluidity. It was observed that the cracking and ultimate breakage of the fibers results in a significant decrease in staple length. Moreover, it has been noted (19) that such modification of fiber properties will influence yarn and/or fabric characteristics. Other studies (12,20,21) have shown that the abrasion resistance of a fabric can be increased by larger-diameter yarns because they reduce localized pressure and thereby decrease wear damage. In addition, further investigations (11,12,22) have indicated that the poor binding of low-twist yarns plays an important role in causing their early breakdown, while high twist forces the yarns to stiffen and causes them to exert high local abrasive pressure that also results in the early destruction of the yarns.

In order to determine the effect of abrasion on fiber morphology, a simple technique of measuring changes in staple length was applied to a cotton/nylon blended fabric that had been subjected to accelerated wear by the Field Evaluation Agency at Fort Lee. The wear observed appeared to be too severe for a cotton/nylon blend. It was desired to determine whether it was the nylon or the cotton that was failing, also if the failure could be related to the mechanical and morphological properties of the fibers and yarns. If a relationship could be established, it would serve as a basis for developing means of improving the quality of the blend. The garments chosen for examination were selected from among a large number that had been subjected to 10 cycles of wear on the Cotton Fabric Course. (Each cycle of wear consisted of 2 traversals and 1 laundering.) Two sample garments were selected for the evaluation: a cotton/nylon sateen and an all-cotton sateen, both of which were worn with the filling side (back) of the fabric to the outside. (The all-cotton sateen, the standard fatigue fabric used by the military departments, is conventionally worn with the filling side to the outside.) The physical and mechanical properties of these two sateens is given in Table XII.

Before conventional techniques for assessing the length distribution of fibers can be used in cotton/nylon blended yarns, the nylon and cotton fibers must first be separated. A standard method for chemically separating these fibers* prescribes a 28 percent solution of hydrochloric acid to dissolve the nylon fibers. This concentration tended to weaken the cotton fibers and resulted in an overall shortening of the staple length distribution. Therefore, after a series of experiments with various concentrations of a comparatively mild hydrochloric acid, an 18.5 percent solution was found to be satisfactory. Fibers taken from the yarns were placed in this solution at a temperature of 15°C for 30 minutes. The fibers were swished gently through the acid to remove remnants of the nylon and then rinsed in distilled water until approximately neutral. In this procedure, the nylon is dissolved without significantly affecting the staple length distribution of the cotton.

* Fiber analysis by chemical separation, Method 3 (23).

TABLE XII

PHYSICAL AND MECHANICAL PROPERTIES OF TWO CARDED SATEEN FABRICS

Fiber and Fabric Properties	Standard Cotton Sateen	Cotton/Nylon* Sateen
Fiber content, %		
Cotton	100	70
Nylon	---	30
Fiber fineness (cotton), in, wxf	.0007 x .0006	.0006 x .0006
Fiber denier	1.5 (equiv)	2.2
Fiber strength (Pressley), psi, wxf	60,500 x 59,500	51,000 x 52,000** 50,000 x 49,000***
Yarn size, cotton count, wxf	14/1 x 9/1	21/1 x 16/1
Yarns/inch, wxf	86 x 57	116 x 80
Yarn twist/inch, Z direction, wxf	17 x 12	20 x 16
Fabric weight, oz/yd^2	9.0	8.2
Fabric weave	5-harness sateen counter of 2	5-harness sateen counter of 2
Fabric break strength (Grab), lb, wxf	146 x 161	164 x 140
Fabric tear strength (Elmen), lb, wxf	7.9 x 11.2	9.7 x 10.1
Flat abrasion resistance (Stoll), 4-lb pressure, 1-lb head, 0 emery, cycles		
Warp face	610	1445
Filling back	1330	1174
Flex abrasion resistance (Stoll), 4-lb tension, 1-lb head, blade 288		
Warp face, wxf	590 x 850	19,800 x 13,200
Filling back, wxf	760 x 620	18,500 x 9,810
Accelerotor abrasion weight loss 16 min, %	38.0	14.0

* Water-repellent treated.
** Essentially the strength of the cotton fibers only, since nylon fibers elongate but do not break.
*** The strength of cotton fibers removed from the unused blend.

In order to establish the validity of using an 18.5 percent hydrochloric acid solution to selectively dissolve the nylon from a cotton/nylon blend, a control test was conducted on samples of cotton staple. The fiber array, prepared on both the treated and untreated yarns by a standard method is illustrated in Figure 11. It indicates that, while the acid treatment (dotted line) changed the shape of the untreated fiber curve to some extent, the observed differences are not significant. In fact, at the high end of the distribution, the acid-treated fibers are somewhat longer than the control; at the middle of the distribution the acid-treated fibers are somewhat shorter than the control; and at the short end there is no difference at all. The quartile lengths** of the two arrays are shown to be identical.

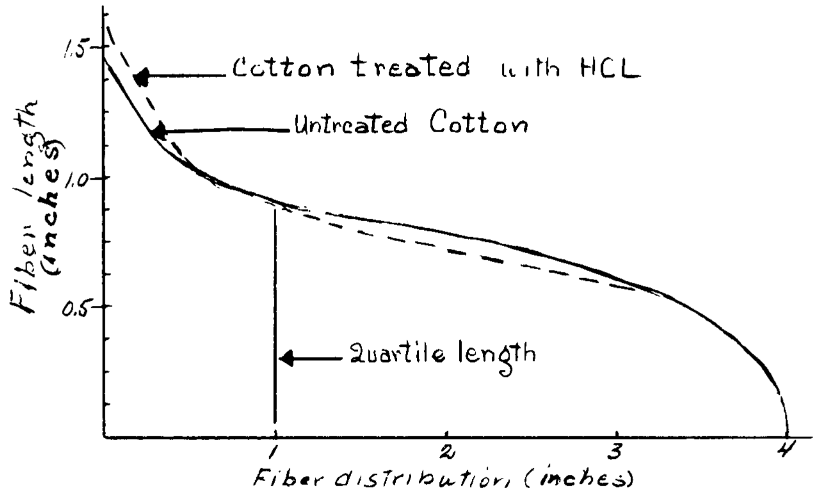


Figure 11 - Staple array - control test

Staple arrays of fibers were prepared from the garments worn on the fabric course and from the same fabrics unused, and the diameter of the fibers was measured as prescribed by the ASTM Manual. Yarn twist was determined by the untwist-twist method described in Federal Specification CCC-T-191b (13). The relative distribution of the nylon and cotton fibers within the yarn structure was determined by imbedding the yarns from the unused fabrics in isobutylmethacrylate that, after hardening, was further imbedded in paraffin. Cross sections were cut from the prepared specimens (by means of a microtome) to a thickness of 15 microns. These cross sections were magnified 500 times by a projecting microscope and the fiber outlines sketched.

Fiber Length. Staple arrays made from fibers removed from the cotton/nylon yarns of the unused fabric revealed a rather uniform distribution of fibers, ranging from a maximum of 1-9/32 to 2/32 inches (Table XIII) in the warp direction and from 1-12/32 to 5/32 inches in the filling direction. The quartile lengths for the warp and filling directions were 1-3/32 and 1-8/32 inches, respectively.

** Quartile length - the fiber length lying 25 percent of the distance along the frequency axis measured from the end of the array of maximum lengths.

When the nylon fibers were dissolved from the unused cotton/nylon blend, it was found that the extremes of the distribution for the cotton fibers were practically identical for both the warp and the filling yarns. However, a rapid dropoff in length occurred beyond the long fiber end, which indicates that very few long cotton fibers were present in the blend. In the warp direction yarns of this sample, it was noted that, toward the tail-end of the distribution, the staple array for the cotton alone was quite close to that of the cotton/nylon. In the filling direction, the differences in the distributions persisted throughout the entire range of fiber length. The quartile lengths were 30/32 and 1-1/32 inches for the warp and filling directions respectively. This amounts to an average reduction of from 5/32 to 7/32 inches.

Quite marked changes in the staple arrays were noted in the cotton fibers removed from the damaged areas of the worn blended-yarn garments. In the warp yarns, the longest and shortest fiber lengths were equivalent to those found in the undamaged areas of the fabric. The quartile fiber length dropped from 30/32 (unused) to 23/32 (damaged) inches. On the other hand, in the filling yarns the longest fiber length observed at the high end of the distribution decreased from 1-12/32 inches in the unused fabric to 1-5/32 inches for the damaged fabric. The quartile length decreased in the filling yarns from 1-1/32 (unused) to 15/32 (damaged) inches. It is interesting to note that although the greatest decrease in quartile fiber length occurred in the filling yarns, as would be expected in garments made with the filling side of the fabric to the outside, nevertheless a significant decrease in mean fiber length occurred in the warp yarns also.

The staple array data are summarized in Table XIII. The boundaries of the arrays of the fibers from the blended yarns are sketched in Figure 12. Photographs of typical staple arrays are shown in Figure 13. The significance of the uniformity ratios for the blended yarns (Table XIII), and particularly for the damaged yarns, requires interpretation.

This type of analysis appears to indicate that it is the cotton fiber in a cotton/nylon blend of this type that is significantly damaged during wear. This raises a question of the engineering design concepts that could be employed to raise the level of the contribution of the nylon. As indicated later, more careful attention may have to be given to the relative diameters of the cotton and nylon fibers in order to obtain, for a given blend composition, the optimum number of fibers of each type.

The staple arrays of fibers removed from the all-cotton fabrics tested on the accelerated wear course (Figure 14) demonstrate a trend similar to that noted for the cotton/nylon fabrics. In the all-cotton fabrics, however, the fibers removed from the damaged areas showed a

TABLE XIII

STAPLE ARRAY DATA

	Fiber Source		Longest Length (in)	Shortest Length (in)	Mean Length (in)	Quartile Length (in)	Uniformity Ratio (in)
1.	Cotton/nylon (unused)	W	1-9/32	2/32	27/32	1-3/32	77
		F	1-12/32	5/32	30/32	1-8/32	74
2.	Cotton from cotton/nylon fabric (unused)	W	1-9/32	2/32	22/32	30/32	70
		F	1-12/32	2/32	23/32	1-1/32	70
3.	Cotton from cotton/nylon garment (damaged area)	W	1-9/32	2/32	17/32	23/32	75
		F	1-5/32	2/32	13/32	15/32	88
4.	Standard all-cotton (unused)	W	1-14/32	2/32	24/32	31/32	77
		F	1-9/32	2/32	22/32	30/32	76
5.	Standard all-cotton garment (damaged area)	W	1-6/32	1/32	17/32	22/32	78
		F	1-3/32	1/32	14/32	17/32	84

Note: All staple arrays scaled to 4 inches in length.

decrease in the longer as well as in the shorter lengths (Table XIII). However, as with the cotton/nylon blends, there appeared to be less loss of short fibers in the warp yarn system and a much greater overall reduction in the length of fibers in the filling than in the warp direction.

Yarn Twist. The twist per inch in the yarns depends on the yarn count and on the twist multiplier* selected for the warp and filling yarn systems. The fiber fineness and length will have a bearing on the twist multiplier selected since long fibers and fine fibers normally require less twist because of the greater number of points of frictional contact among adjacent fibers. However, as yarn count becomes finer, more twist is needed to offset the loss in strength due to the reduced mass of the yarn structure. The data given in Table XII indicate that the twist multipliers used for the warp and filling yarns would be 4.50 x 4.00, which is closer than normal. Conventional twist multipliers are 4.75 for the warp and 3.50 for the filling. Accordingly, any differences observed in the behavior of the yarns in the fabrics was presumably more a function of yarn count than of any other conventional yarn parameter. The counts of the yarn in the cotton/nylon blended fabric were 21/1 in the warp and 16/1 in the filling, whereas the respective yarn counts in the standard cotton fabric were 14/1 and 9/1. Since the twist multiplier for the warp yarns (4.50) was less than that normally used (4.75), it is probable that the contribution of the warp yarns

* Twist multiplier = $\dfrac{\text{twist per inch}}{\sqrt{\text{yarn count}}}$

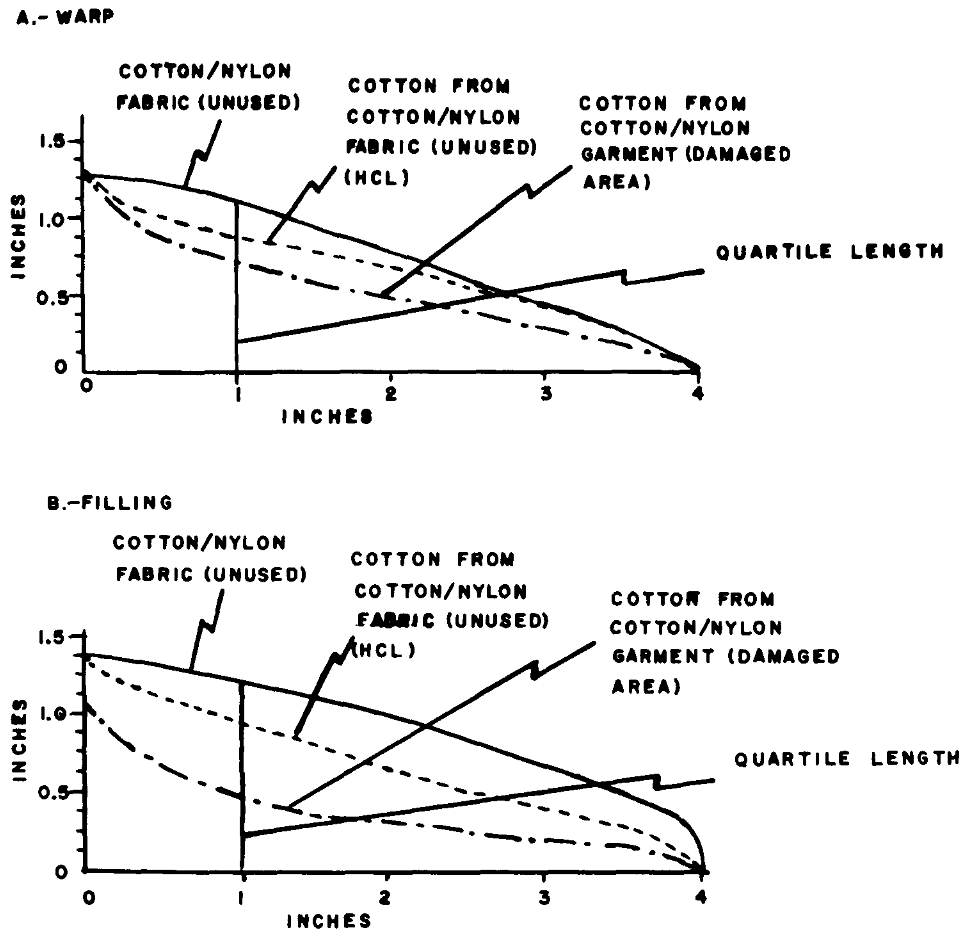
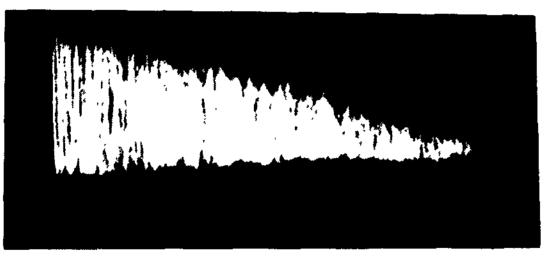
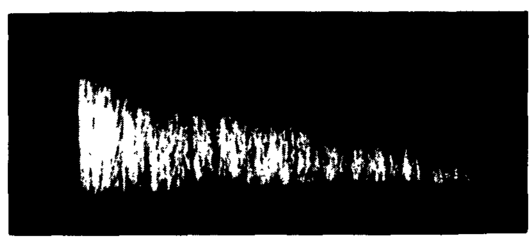


Figure 12 - Staple arrays of fibers from blended yarns



a. Fibers from warp yarns of the cotton/nylon blend



b. Cotton fibers from warp yarns of the cotton/nylon blend

Figure 13 - Typical staple arrays

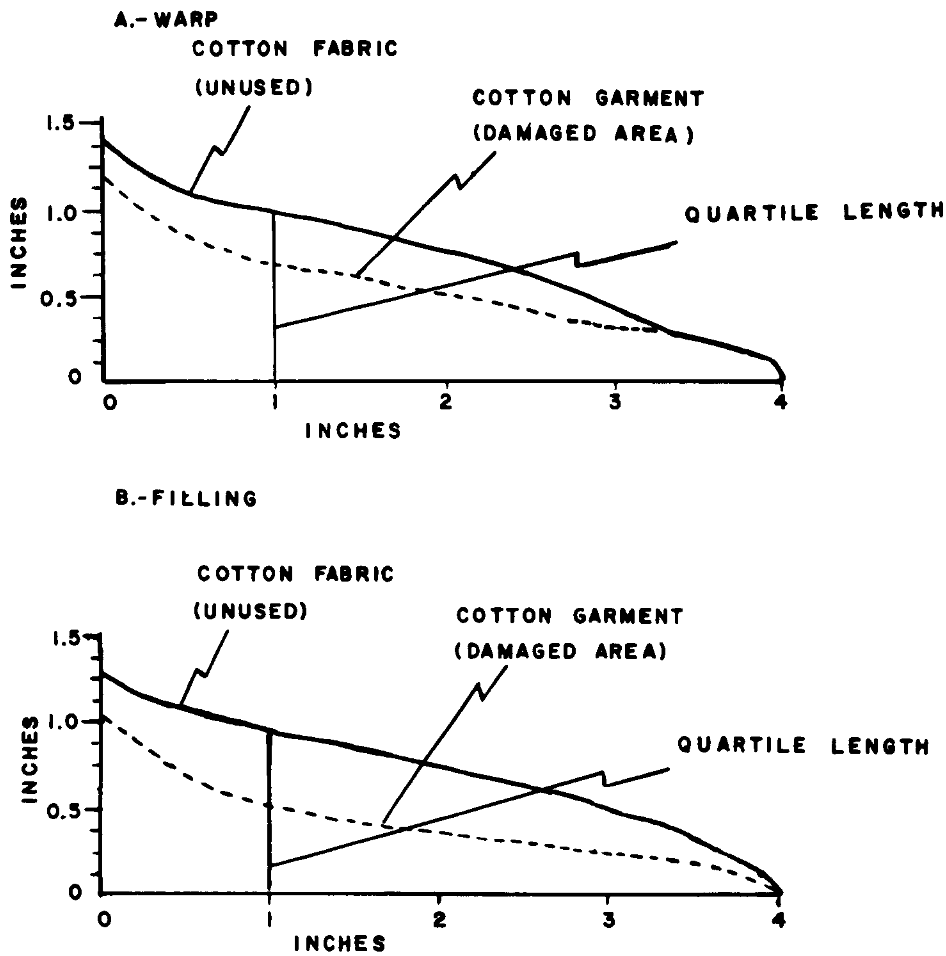
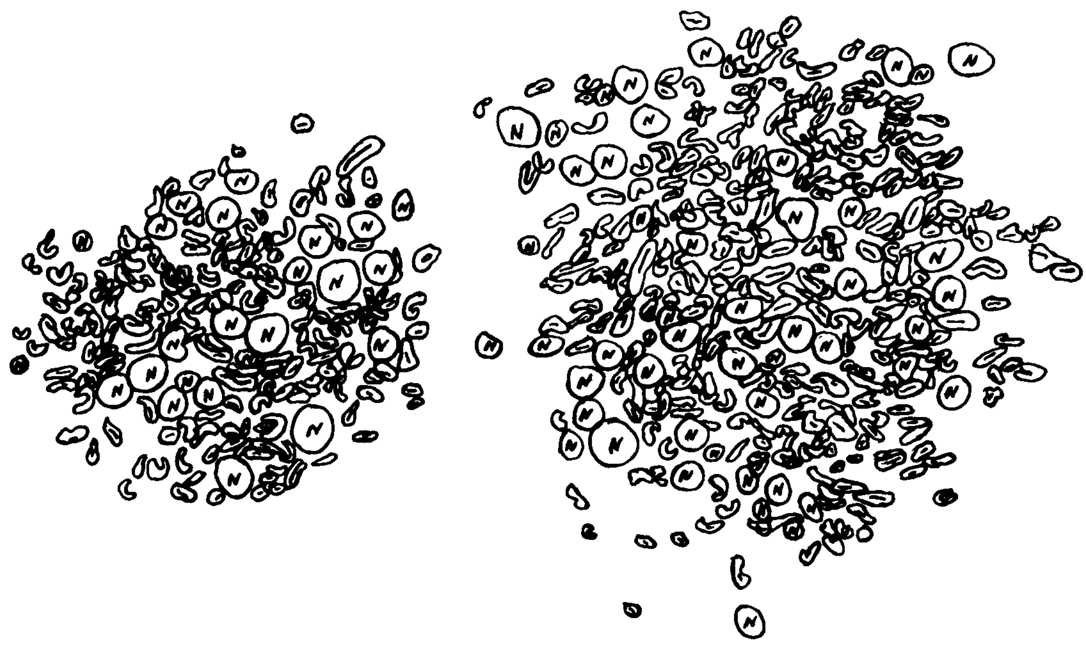


Figure 14 - Staple arrays of fibers from all-cotton yarns

to the abrasion resistance noted would be less than in an optimally twisted construction. Moreover, it is conceivable that reduction in twist could affect the abrasion resistance of the finer blended warp yarns to a greater extent than the coarser cotton warp yarns because of the smaller mass of the former. On the other hand, the twist multiplier in the filling direction was higher (4.00) than normally used (3.50). If this value is above the point of optimum twist in the strength-twist relationship, it could lead to more rapid failure as a result of its reduced strength and the tendency to stiffness. In addition, the high count (small diameter) of the cotton/nylon blended yarns reduces the overall number of fibers in the cross section of these yarns and this would naturally lead to a greater percentage loss in stress support value as individual fibers are abraded.

Fiber Diameter and Distribution. The denier of the nylon staple used in making the blended fabric was 2.2. The equivalent denier of the cotton fibers was approximately 1.5. Since the density of nylon is 1.14 as compared to 1.54 for cotton, it would be natural to expect the cross-sectional area of the nylon fibers to be considerably larger than that of the cotton fibers. This is confirmed by sketches made of yarn cross sections (Figure 15.) What seems to be even more important from the standpoint of wear, however, is the rather uneven distribution of the nylon and cotton, particularly in the warp yarns. The nylon fibers appear bunched and not at all uniformly distributed throughout the yarn structure. Obviously, this poor distribution must have resulted when the fibers were blended in sliver form at the drawing operation. Probably a much more uniform blend could have been produced by blending the fibers in a sandwich configuration prior to the picking process. It is difficult to assess the influence of this nonuniformity on abrasion resistance, but in the absence of contrary data, it is logical to assume that it may be a significant factor.



Warp yarns Filling yarns

Figure 15 - Yarn cross sections (500x)

Fiber Strength. The strength of the all-cotton and cotton/nylon fibers was measured by the Pressley technique. During the measurements, it was observed that the nylon fibers stretched up to the point at which the load was transferred to the cotton fibers. After this, rupture occurred and, as anticipated in tests of this type on blended materials, the nylon fibers contributed load-supporting value only to the point of rupture or to the point at which their elongation was equivalent to that of the cotton fibers. Thus a major portion of the strength of the nylon fibers is not realized in a blend of this type. This observation was confirmed by the results of tests made on the fabrics (Table XII). These tests showed the Pressley strength of the cotton fibers from the cotton/nylon blend to be practically identical to that of the fibers from the all-cotton fabric. Therefore, differences in performance between the two fabrics cannot be attributed to differences in cotton fiber strength.

Microscopic Examination of Fabric. Microscopic examination of the worn areas of the cotton/nylon fabric confirmed the conclusion drawn from the staple arrays, i.e., that the cotton fibers had abraded and ruptured first, leaving relatively few nylon fibers in the yarn cross section to sustain further wear action. It is conceivable that, in a sense, the presence of the relatively large nylon fibers might have contributed to the more rapid failure of the cotton under the rather unusual wear conditions of this study.

It is evident that more attention must be given to the microstructure of the yarns and fibers in blended materials of this type before causes can be assigned to wear failure and before constructive engineering design steps can be taken to enhance wear resistance. Rather than drawing any definite conclusions from this rather cursory study, it would be desirable to consider the factors that have been observed in this experiment and to use them as a basis for planning a more definitive study in which a more precise assessment can be made of the role of such factors as fiber density, fiber diameter, fiber length distribution, yarn count, and yarn twist on observed wear. It is anticipated that experiments involving a consideration of this great variety of parameters will be undertaken in the future as part of the planned development program on cotton/nylon blended fabrics.

e. Influence of Work to Rupture

As a result of the increasing number of high tenacity man-made fibers which are being introduced into the textile market, the potential for major increases in the wear resistance of textiles has never been more promising than at the present time. Increase in wear life that may double that of the best presently existing textile structures is forseeable in the not-too-distant future. This increase has already been achieved for hosiery made from stretch nylon or reinforced with nylon yarn.

Recently, there has been a resurgence of interest in wear phenomena (23), partly as a result of the development of new materials and partly as a result of the formulation of new theories of wear that have been published during the past decade (5). The high work-to-rupture which is characteristic of the new man-made fibers (the polyamides, polyesters, polyolefins, and many others) is probably their most important contribution to wear. Hamburger (24) has obtained a linear relationship between "energy coefficients" and "durability coefficients" for yarns composed of different fiber species. His energy coefficients are the slopes of the lines to the mean ordinates of the percent ultimate strength vs. percent elongation plots of the stress-strain curves of the yarns after mechanical conditioning; his durability coefficients were computed by measuring the slope of the lines determined by the origin and mean ordinates of strength loss vs. cycles plots of his abrasion data. A similar study made in the Natick Laboratories relates the work-to-rupture of a series of cotton/nylon yarns and their abrasion resistance as evaluated by the method of Walker and Olmstead (25). The Natick data show a significant increase in abrasion cycles with increasing work, but at the point representing the highest measured work-to-rupture there is much more than a proportional increase in abrasion resistance (Figure 16). This point is for a yarn made of 100 percent spun nylon. Apparently,

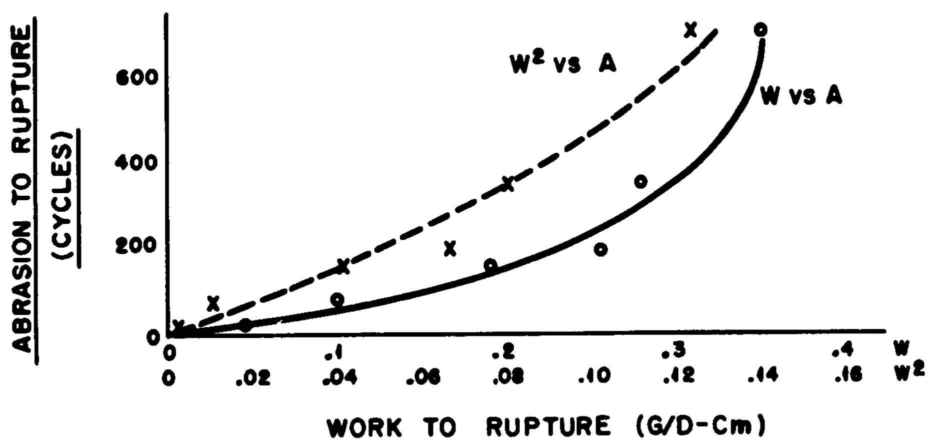


Figure 16 - Relationship of abrasion and work-to-rupture of nylon/cotton blended yarns

there must be factors other than work-to-rupture which govern the abrasion resistance of yarns of this type. As Figure 16 shows, the linearity of the relationship is increased somewhat by squaring the work-to-rupture.

An attempt was made to apply this technique in terms of the energy-absorbing characteristics of component fibers or yarns to the assessment of the abrasion resistance of 2/2 wool serges blended with

15 percent and 30 percent of nylon, polyester, viscose, and modacrylic fibers. The test was carried out on the Wool Fabric Wear Course at Fort Lee, Virginia. The wear course consists of a series of obstacles that produce a type of wear normally associated with combat conditions: sand cover points, concrete culverts, wood and gravel crawls, log road blocks, railroad embankments, tank traps, revetments, etc. The wear that results is represented by holes, tears, frays, and wear areas. These are rated numerically according to their frequency and severity in order to arrive at a wear score. This score is used as the basis for comparing the different fabric types. In this test, the wear scores ranged from 8.5 for a nylon blend (good wear) to 40.2 for a viscose blend (poor wear).

Two systems were used to compare the wear scores of the uniforms with the energy-absorbing characteristics of their component materials. In one, the wear scores were plotted against one-half the product of the strength-to-rupture and the elongation-to-rupture of the component yarns. This would correspond to the work-to-rupture of the yarn if the assumption were made of linearity of the stress-strain curve. In the other system, the wear scores were plotted against a factor derived by weighting the work-to-rupture values of the component fibers by their percentage composition in the blend. This latter procedure has the disadvantage of not being directly comparable for the various fiber types because of the different physical forms in which the fiber species have been evaluated in studies reported in the literature. Figure 17 represents the wear scores plotted against the work coefficients computed from the yarn strength and elongation data. Figure 18 represents wear scores plotted from weighted fiber data. The agreement is quite good for the former but indicates only a trend in the latter.

The general information obtained from this type of data is quite useful and sheds light on mechanisms governing the wear resistance of textile fabrics. However, we are still far from being able to predict, on an exact quantitative basis, how long a given man-made-fiber fabric or combination fabric will wear. Nevertheless, it is reasonable to expect that, if fibers having the right mechanical properties are made into fabrics, their field performance will reflect to a reasonably satisfactory degree expectations based upon their mechanical properties.

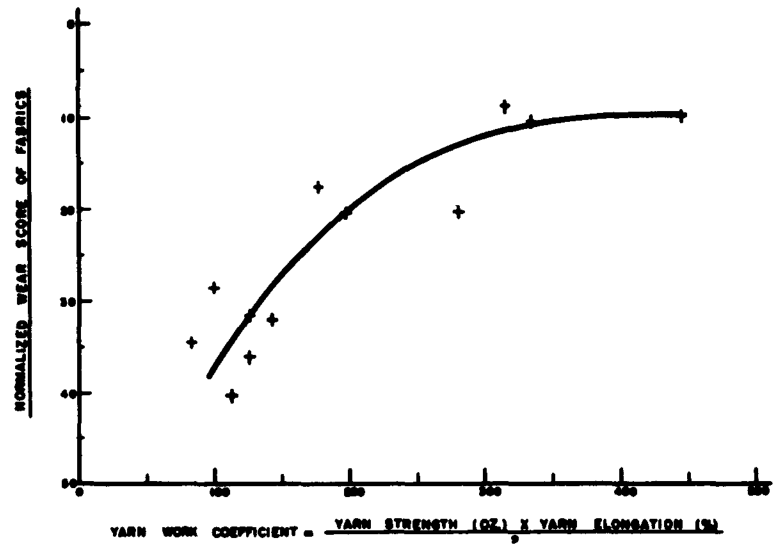


Figure 17 - Wear course scores and work coefficients

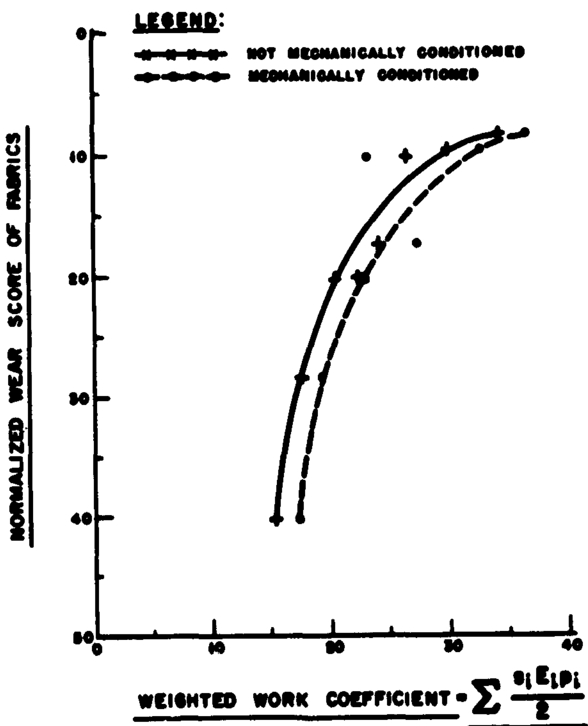


Figure 18 - Wear course scores and
weighted work coefficients

4. Wear Trials

a. Nyco Blends*

As a part of a continuing program to provide combat clothing with increased durability, the U. S. Army Natick Laboratories have developed a series of optimally engineered experimental cotton/nylon (Nyco) sateen weave fabrics for thermal protection. Two of these, plus the standard carded cotton sateen, were evaluated on the Cotton Fabric Wear Course at Fort Lee, Virginia. One fabric (9.7-oz) was produced with a carded cotton warp and nylon filament filling; the other (8.0-oz) was produced from carded singles yarns spun from a 67/33 cotton/nylon 420 blend for both warp and filling. The fabrics were made into trousers, with the filling side of the material to the outside.

Sixty-four medium-size men were each issued 2 pairs of standard control trousers and instructed in the proper manner of traversing the wear course. At the end of a 6-day training period, the test subjects had been thoroughly trained and conditioned to make a minimum of 3 cycles of the course per day. To obtain the most adept test subjects, only the 40 men who had become most proficient in the proper manner of traversing the course were used in the test. The 40 test subjects were divided into two groups of 13 men each and one group of 14. In the early stages of the test, 3 men were lost for medical reasons. Each of the remaining 37 men was assigned 1 pair of each of the three types of test trousers for wear over the course. During every cycle, each of the three groups of test subjects wore a pair of trousers of a different type fabric. Each of the test trousers was worn by the same man for 11 cycles of the course. After each cycle, the trousers were laundered in the Mobile Laundry. All failures were recorded according to the Field Evaluation Agency's wear score system.

The average cumulative wear scores for each type of fabric, calculated for each cycle of the wear course, are shown in Table XIV and Figure 19.

* This section is based on "An Engineering Test on Wear Resistance of Cotton/Nylon Fabrics" by J. M. Matthews (26).

TABLE XIV

AVERAGE CUMULATIVE WEAR SCORES BY CYCLES OF WEAR*

Fabric**	Cycles 1	2	3	4	5	6	7	8	9	10	11
Cloth, cotton/nylon sateen, 9.7-oz, with carded cotton warp and nylon filament filling	0.0	0.3	1.2	2.5	3.8	4.6	5.9	7.5	8.7	11.1	12.2
Cloth, cotton/nylon sateen, 8.0-oz, 67/33, 420 blend with carded singles warp and filling yarns	0.3	0.4	2.0	4.4	7.1	10.7	14.2	19.0	23.4	25.8	30.6
Cloth, cotton carded sateen, 8.5-oz (standard)	1.4	2.4	4.2	9.2	12.4	15.1	20.0	25.5	31.6	36.2	42.1

* 1 cycle = 2 traversals
** 37 trousers of each type

These data show that at the completion of 11 cycles of wear the experimental 9.7-oz cotton/nylon sateen with carded cotton warp and nylon filament filling was significantly* more wear resistant than the other fabrics. The experimental 8.0-oz cotton/nylon, 67/33, 420 blend, carded sateen was significantly more wear resistant than the standard 8.5-oz carded cotton sateen.

* Statistical significance at 5% probability level.

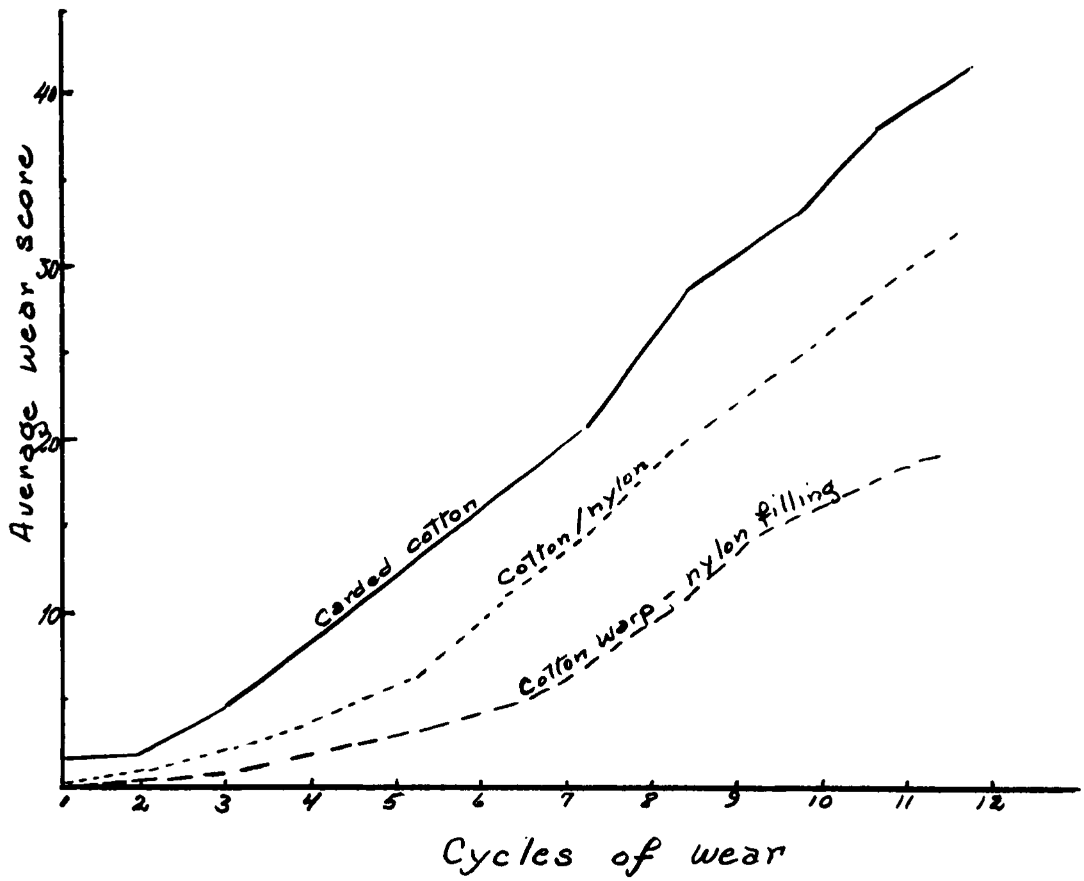


Figure 19 - Average cumulative wear score versus cycles of wear on cotton fabric course

Table XV shows the distribution in the three types of fabric of wear areas, tears, and hole failures by type, size, degree, and number, after 11 cycles of wear. It will be noted that the total number of holes is greater in the cotton/nylon blend than in the standard sateen, although the cotton/nylon blend has a significantly lower wear score. Closer scrutiny of Tables XIV and XV reveals that the wear score of the standard sateen is made higher by the more frequent occurrence of wear areas and the greater percentage of holes larger than 1/4 inch.

A paired comparison analysis was made of the number of times holes appeared first in each fabric for each of the 37 paired trousers and these data, shown in Table XVI, substantiate the findings given in Table XIV and Figure 19.

TABLE XV

NUMBER AND PERCENTAGE OF FAILURES AT EACH DEGREE OF SEVERITY AFTER 11 CYCLES OF WEAR (22 TRAVERSALS)

Fabric	Wear Area Degree (sq in) 1 Up to 4	2 Over 4 & Incl 9	Hole Diameter Degree (inches) 1 Up to ¼	2 Over ¼ & Incl ½	3 Over ½ & Incl 1	4 Over 1 & Incl 1½	5 Over 1½ & Incl 2	6 Over 2	Total
Cotton/nylon sateen, 9.7-oz, carded cotton warp, nylon filament filling									
Number	29	4	44	4	2	0	0	2	52
Percentage	not given		84.7	7.7	3.8	---	---	3.8	100
Cotton/nylon sateen 8-oz, 67/33, 420 blend, carded singles warp & filling									
Number	7	0	145	11	8	1	1	6	172
Percentage	not given		84.2	6.4	4.7	0.6	0.6	3.5	100
Cotton carded sateen, 8.5-oz (standard)									
Number	51	3	105	23	12	12	3	8	163
Percentage	not given		64.4	14.1	7.4	7.4	1.8	4.9	100

TABLE XVI

NUMBER OF TIMES HOLE APPEARED FIRST IN EACH FABRIC FOR EACH OF THE 37 PAIRED TROUSERS

Fabric	No. of Times First Appearance of Hole	Tie
Cloth, cotton carded sateen, 8.5-oz. (Std.) control	30*	
Cloth, cotton/nylon sateen, 9.7-oz., with carded cotton warp and nylon filament filling	5	2
Cloth, cotton carded sateen, 8.5-oz. (Std.) control	24*	
Cloth, cotton/nylon sateen, 8.0-oz. 67/33, 420 blend, with carded singles warp and filling yarns	9	4
Cloth, cotton/nylon sateen, 8.0-oz., 67/33, 420 blend, with carded singles warp and filling yarns	25*	
Cloth, cotton/nylon sateen, 9.7-oz., with carded cotton warp and nylon filament filling	10	2

* Significant at the 5% probability level.

b. Wool Serge Blends

Man-made fibers are being used increasingly in blends with wool. This not only extends the domestic supply of wool, which is important in military applications, but it creates fabrics with a new spectrum of properties. In 1951, a series of blended serges was manufactured for joint Army Quartermaster-Air Force evaluation. They included modacrylic, polyester, and 3- and 5.5-denier viscose blends with wool at 15 and 30 percent levels and nylon blended with wool and with wool and viscose. Both 56s and 60s wool grades were used.

Evaluation of the wear resistance of wool blends is extremely difficult. One problem is the determination of a valid end point for each test. During the abrasion of blends, the wool is selectively removed. Although the fabric that remains is different in appearance and in many of its physical properties, it still will have considerable abrasion resistance before the normal end point (appearance of a hole) is arrived at. Laboratory evaluations were made on the Stoll-Flex Abrader, with an end point at the first sign of threadbareness and also at complete rupture; on the Sand Abrader, to the first hole; and on the Wool Fabric Course at Ft. Lee, using the conventional FEA wear score system (see Table V, p. 11). Table XVII shows the differences in wear score obtained from the blends on the fabric course.

TABLE XVII

WEAR SCORES OF WOOL BLENDS

Blend	Weave	Wear Score
70/30 60^s wool/nylon	twill	8.5
70/30 60^s wool/polyester	"	9.8
70/30 60^s wool/modacrylic	"	10.1
85/15 60^s wool/polyester	"	17.7
85/15 60^s wool/modacrylic	"	20.2
70/20/10 60^s wool/viscose/nylon	"	20.3
70/30 60^s wool/viscose (3 den.)	"	28.8
70/30 56^s wool/viscose (3 den.)	"	31.7
70/30 60^s wool/viscose (5.5 den.)	"	32.2
100% 60^s all-wool control	"	34.9
100% 56^s all-wool control	"	36.2
85/15 60^s wool/viscose	"	40.2
70/30 60^s wool/viscose	sateen	48.2

On the wear course, the non-viscose blends showed the highest level of wear resistance, with the nylon, polyester, and modacrylic blends leading. The blends with a 30 percent of non-wool content showed better wear resistance than those with 15 percent. The denier of the viscose and the grade of the wool appeared to have little influence on wear. The fabrics lowest in wear resistance in this test were the viscose blends and the all-wools.

The superior wearing qualities of nylon have long been recognized and experience with polyesters has indicated that their wear resistance is very close to that of nylon. That the modacrylics ranked so closely with the polyester blends on the wear course was surprising because laboratory data had indicated their wear resistance to be somewhat lower than the polyesters. Conventional laboratory instruments have been observed to rank fabrics containing nylon higher and fabrics containing modacrylic fibers lower than does the wear course, perhaps because of the high temperatures caused by the interaction between the modacrylic fibers and the metal abrader of the tester. The rankings found on the Sand Abrader were much closer to the wear course rankings than the results of the Stoll test (Table V).

c. Correlation Between Laboratory Abrasion and Accelerated Field Wear

Wear resistance is a major objective in the design of military textiles, yet the mechanisms used to arrive at this objective are often based on so-called "good design" practices that do not always guarantee a high level of wear in the field. Interpretation of test data in terms of actual wear, especially of fabrics containing man-made fibers or special finishes, remains uncertain and the selection of appropriate testing devices from the many that are available continues to present a problem.

The need has long been recognized for validating laboratory abrasion testing against actual wear in the field. The Natick Laboratories have conducted several studies to shed light on this problem. In their most comprehensive study (27), conducted in 1948, garments made from a broad range of fabric types were worn on the accelerated wear course at Fort Lee, Virginia; the same fabrics were tested in the laboratory on the Stoll-Flex Abrader. By using a weighting factor, it was possible to show a significant relationship between the tests. However, weighting factors have their limitations because they are usually applicable only to the group of fabrics selected and therefore they cannot be generalized for other fabric types without further testing.

In recent years, the development of Nyco blends for thermal protection has restimulated interest in wear resistance because of the potentially superior performance of nylon/cotton combinations. Therefore it has been considered desirable to obtain information on the overall serviceability of these blends, compared to the all-cotton fabrics that have been standard for so long, and at the same time to obtain data that would facilitate establishing a realistic correlation between the accelerated wear course and laboratory abrasion testing. In view of the lack of adequate information on the relative performance of blended fabrics of the Nyco type, comparative data are needed to provide relevancy to the testing programs being conducted.

The fabrics now under study are based on the 8.5-oz carded sateen, which is the standard fatigue fabric used by the military. This is logical, since there is a wealth of comparative data available on the standard fabric. Four variations of this construction were designed and manufactured for laboratory and field correlation studies:

An all-cotton control, meeting the new requirements (28) for carded sateen established in 1961. These new requirements consist primarily of setting an upper limit for weight and of increasing the warp and filling breaking strength, thus compelling the manufacturer to use a better grade of cotton. This change reverses the trend, toward a lowered quality of carded sateen, which had occurred over the years as a result of competition for government business, and upgrades the fabric to correspond more closely to the original construction that had been designed and purchased in the early post World War II period.

An intimate blend of nylon and cotton, containing equal parts by weight of the two fibers. This fabric corresponds in fiber content and blend type to the Nyco fabrics, which provide protection against high energy thermal radiation.

An ortho mixture, consisting of an all-cotton warp and a nylon filament filling. On the basis of a test conducted on a similar fabric designed for the Marine Corps, this construction is expected to provide a high level of wear resistance, but it would not be as suitable for thermal protection as the intimate blend.

A heavier weight intimate blend of nylon and cotton, in equal proportions. This fabric is designed to have a tight construction suitable for the application of the Quarpel finish. It is anticipated that it will be a satisfactory substrate for the newly developed "Fire-Chem" treatment (29).

In general, all of the fabrics are heavier in weight than would have been desired for an ideal experiment. However, for the comparisons which will be made, the difference in weight between the actual and the ideal fabrics is not excessive.

Physical test data for the four experimental sateens are presented in Table XVIII.

TABLE XVIII

PHYSICAL PROPERTIES OF EXPERIMENTAL SATEENS

Fabric Properties	All-Cotton	Cotton/Nylon	Cotton Warp/ Nylon Filling	Heavyweight Cotton/Nylon*
Weight, oz/yd^2	8.9	9.9	9.7	11.5
Texture, yarns/in (wxf)	86x58	86x57	86x57	107x62
Yarn size, cotton count (wxf)	15/1x9/1	13/1x8/1	15/1x700	13/1x8/1
Breaking strength, (Grab) lb, (wxf)	158x148	231x243	162x523	297x285
Trapezoid tear str, lb, (wxf)	13x17	34x36	14x137	46x41

Note: All fabrics: 5-harness sateen, counter of 2, staple nylon type 420, filament nylon type 680, fabric width 41.5". Fabrics manufactured by J. P. Stevens, TEL project - Phase I NYCO Series.

* All measurements were made on the untreated fabric. The untreated fabric was used in the FEA tests; the Quarpel-treated fabric was used in the field trial.

Laboratory abrasion tests were made on the BFT Mark III Abrader (30) and the new Sand Abrader (31). It had been planned to also use the Stoll-Flex Abrader, but preliminary evaluations indicated that the conventional one-inch-width Wyco specimens take an excessively long time to wear through and narrower-width specimens give results that are highly variable. In order to make the BFT Mark III testing more analagous to the Stoll, the flex blade was fitted with a carbide steel edging identical to that normally used for the Stoll blades. Prior to the initiation of testing, the blade was "broken-in" in accordance with standard procedures: by abrading it against a 10-oz duck for 30,000 cycles. Since sateens used in military items are made up with the back or filling flush side to the outside, the abrasion tests were conducted only on the back side of the fabrics. The levels of abrasion resistance found in the tests (Table XIX) indicate that the fabrics were sufficiently different in this property to provide a basis for correlating with accelerated field wear and probably with normal field wear.

TABLE XIX

ABRASION RESISTANCE OF EXPERIMENTAL SATEENS

Laboratory Test	All-Cotton	Cotton/Nylon	Cotton Warp/ Nylon Filling	Heavyweight Cotton/Nylon
Sand abrasion* (cycles to holes)	3500	8500**	6700**	9000
BFT Mark III abrasion (cycles to rupture)				
As received	1050	5280	3080	8620
Chloroform extracted	690	1830	1780	2380

* Data from reference 31
** A repetition of tests showed both values closer to 7500

Conventional statistical techniques will be used to establish the presence or absence of correlations between laboratory and accelerated wear course test data. A factor which may limit the quantitative approach to the correlations is the small number of points (four) which form the basic data. However, it is assumed that the levels of wear of the fabric types will be sufficiently distinct to make differences between them readily discernible. The plotting of scatter diagrams and the computing of rank correlation coefficients "ρ" will provide general information about the linearity and strength of the associations between the data. The findings of these analyses will determine the desirability of using the numerical data to compute correlation coefficients (r) and standard errors of estimate. The use of weighting factors will not be considered unless the validity for doing so can be established mechanistically. Even if a basis for weighting appears reasonable, the assignment of significance to the resulting correlations must await verification from an independent series of fabrics.

Preliminary reports from the accelerated wear course indicate that the all-cotton sateen shows the least wear resistance and the cotton/nylon blends show the greatest wear resistance. While this was expected, the fact that the three blended fabrics are closely clustered was not expected and may make the establishment of the correlations more difficult. It appears that it may be necessary to continue the accelerated wear course tests through a second season to segregate the wear into more discernible levels of magnitude. It is conceivable that actual field trials may discriminate among the blends more readily. Accordingly, any definite statement at this point must be held in abeyance.

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